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RESEARCH AND DEVELOPMENT IN NATURAL LANGUAGE UNDERSTANDING AS PART OF THE STRATEGIC COMPUTING PROGRAM

FINAL REPORT

Damaris Ayuso, Madeleine Bates, Robert Bobrow, Marie Meteor, Lance Ramshaw, Varda Shaked,
Ralph Weischedel

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Prepared by:

BBN Systems and Technologies Corporation
10 Moulton Street
Cambridge, MA 02138

Prepared to:

Defense Advanced Research Projects Agency (DARPA)
1400 Wilson Blvd.
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Scientific Officer:
Dr. Alan R. Meyrowitz



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<p>→ This report includes a collection of points reporting natural language research. The problem of acquiring linguistic knowledge is the chief obstacle to widespread use of natural language technology. Chapter 1 and 4 report results of five to tenfold increase in our productivity in moving the Janus and Parlance™ natural language shells to new application domains. The ability of natural language systems to cooperatively handle novel, errorful, or incomplete forms is also critical; chapters 3 and 5 report new techniques for intelligently and gracefully respond to such forms. Chapter 2 reports on an implementation of a discourse module for understanding definite reference.</p>			
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Table of Contents

1. Portability in the Janus Natural Language Interface	1
1.1 Introduction: Motivation	1
1.2 What KNACQ Does	1
1.3 KNACQ Functionality	2
1.3.1 Concepts and Classes	2
1.3.2 Attributes	3
1.3.3 Caseframe Rules	3
1.3.4 Adjectives	3
1.4 Experience Thus Far	4
1.5 Related Work	4
1.6 Conclusions	5
References	5
2. Discourse Entities in Janus	7
2.1 Introduction	7
2.2 Meaning Representation for DE Generation	8
2.3 Context Dependence of Discourse Entities	9
2.4 DEs for Independent Indefinite NPs	10
2.5 Dependent NPs	11
2.5.1 Dependent Indefinite NPs	11
2.5.2 Dependent Definite NPs	13
2.6 Non-Linguistic Discourse Entities	14
2.7 Conclusions and Further Work	14
2.8 Acknowledgments	15
References	15
3. A Metaplan Model for Problem-Solving Discourse	17
3.1 Introduction	17
3.2 Plan Building Metaplans	18
3.2.1 Plan Refining Metaplans	18
3.2.2 Variable Constraining Metaplans	19
3.3 Query Metaplans	19
3.3.1 Plan Feasibility Queries	19
3.3.2 Slot Data Queries	20
3.4 Comparison with Other Plan-Based Discourse Models	21
3.5 Applications and Implementation	22
3.6 Extensions to the Model and Areas for Further Work	23
References	25

4. Rapid Porting of the ParlanceTM Natural Language Interface	27
4.1 Introduction	27
4.1.1 The Navy's IDB Database	27
4.1.2 The Parlance Interface	27
4.1.3 The Learner	28
4.2 Configuring Parlance	29
4.3 Conclusions	31
References	31
5. Strategies for Effective Paraphrasing	33
5.1 Introduction ¹³	
5.2 Problems and Strategies	34
5.3 Architecture	35
5.3.1 The Understanding Component: IRUS-II(TM) NL Software	35
5.3.2 The Generation System: SPOKESMAN	37
5.4 Paraphrasing Syntactic Ambiguities - an Example	38
5.4.1 Phase 1: The Problem Recognizers	38
5.4.2 Phase 2: Translating from WML to Text Structure	40
5.5 Using the Paraphraser in a Cooperative Dialog System	41
5.6 Comparison with Other Work	43
5.7 Conclusion	43
References	44

¹³We would like to thank Lance Ramshaw for his invaluable help in understanding the inner workings of RUS and suggestions of where it³³ could be augmented for our purposes, and Dawn MacLaughlin for her implementation of Parrot, the initial version of our paraphraser. We would also like to thank Ralph Weischedel, Damaris Ayuso, and David McDonald for their helpful comments of drafts of this paper and Lyn Bates for early inspirations.

List of Figures

Figure 1:	Subplans of IncreaseGroupReadiness	18
Figure 2:	<i>Build-Plan, Build-Subplan, and Build-Subaction</i>	18
Figure 3:	<i>Instantiate-Var</i>	19
Figure 4:	<i>Add-Constraint</i>	19
Figure 5:	<i>Ask-Pred-Value</i>	20
Figure 6:	<i>Instantiate-Var and Build-Subaction</i>	20
Figure 7:	<i>Ask-Fillers</i>	20
Figure 8:	<i>Sort-Set-by-Scalar and Limit-Cardinality</i>	21
Figure 9:	Architecutre of the Paraphraser	34
Figure 10:	Parse Paths	39
Figure 11:	Text Structure for Generation	43

1. Portability in the Janus Natural Language Interface

Ralph M. Weischedel, Robert J. Bobrow, Damaris Ayuso, Lance Ramshaw¹

1.1 Introduction: Motivation

Portability is measurable by the person-effort expended to achieve a pre-specified degree of coverage, given an application program. Factoring an NL system into domain-dependent and domain-independent modules is now part of the state of the art; therefore, the challenge in portability is reducing the effort needed to create domain-dependent modules. For us, those are the domain-dependent knowledge bases, e.g., lexical syntax, lexical semantics, domain models, and transformations specific to the target application system.

Our experience in installing our natural language interface as part of DARPA's Fleet Command Center Battle Management Program (FCCBMP) illustrates the kind of portability needed if NL applications (or products) are to become widespread. We demonstrated broad linguistic coverage across 40 fields of a large Oracle database, the Integrated Data Base (IDB), in August 1986. A conclusion was that the state of the art in understanding was adequate. However, the time and cost needed to cover all 400 fields of the IDB in 1986 and the more than 850 fields today would have been prohibitive without a breakthrough in knowledge acquisition and maintenance tools.

We have developed a suite of tools to greatly increase our productivity in porting BBN's Janus NL understanding and generation system to new domains. KREME [1] enables creating, browsing, and maintaining of taxonomic knowledge bases. IRACQ [2] supports learning lexical semantics from examples with only one unknown word. Both of those tools were used in preparing the FCCBMP demonstration in 1986. What was missing was a way to rapidly infer the knowledge bases for the overwhelming majority of words used in accessing fields. If such a tool were available, then one could further bootstrap using IRACQ.

We have developed and used such a tool called KNACQ (for KNowledge ACQuisition). The efficiency we have experienced results (1) from identifying regularities in expression corresponding to regularities in the domain model and its function and from (2) requiring little information from the user to identify which regularities apply to which domain structures.

Our long-term goal is to support a seamless interface making simultaneous access to multiple, heterogeneous application systems possible. We have focused thus far on access to expert systems.

1.2 What KNACQ Does

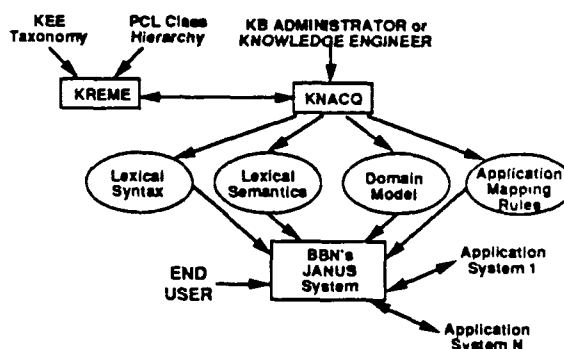


Figure 1: Role of KNACQ

KNACQ assumes that a taxonomic model of the domain exists, such as that typical in many expert

¹This paper is a reprint of a paper that appears in *Proceedings of the Speech and Natural Language Workshop*, Morgan Kaufmann Publishers, Inc., San Mateo, CA, February, 1989.

systems, and assumes that it is encoded in an axiomatizable subset of KREME [4]. At this point we have built translators for transforming KEE taxonomies and PCL hierarchies into KREME structures.² The browsing facilities, graphical views, and consistency checker of KREME are therefore at the disposal of the knowledge base administrator or knowledge engineer when using KNACQ.

Using KREME users may select any concept or role for processing. KNACQ presents the user with a few questions and menus to elicit the English expressions used to refer to that concept or role. There are five cases corresponding to syntactic regularities that reflect functional regularities.

To illustrate the kinds of information that must be acquired consider the examples in Figure 2. To handle these one would have to acquire information on lexical syntax, lexical semantics, and mapping to expert system structure for all words not in the domain-independent dictionary. For purposes of this exposition, assume that the following words, *vessel*, *speed*, *Vinson*, *CROVL*, *C3*, and *deploy* are to be defined. A *vessel has a speed of 20 knots* or a *vessel's speed is 20 knots* would be understood from domain-independent semantic rules regarding *have* and *be*, once lexical information for *vessel* and *speed* is acquired. In acquiring the definitions of *vessel* and *speed*, the system should infer interpretations for phrases such as *the speed of a vessel*, *the vessel's speed*, and *the vessel's speed*.

The vessel speed of Vinson
The vessels with speed above 20 knots
The vessel's speed is 5 knots
Vinson has speed less than 20 knots
Its speed
Which vessel have a CROVL of C3?
Which vessels are deployed C3?

Figure 2

Given the current implementation, the required knowledge for the words *vessel*, *speed*, and *CROVL* is most efficiently acquired using KNACQ: names of instances of classes, such as *Vinson* and *C3* are automatically inferred from instances in the expert system taxonomy; and knowledge about *deploy* and its derivatives would be acquired via IRACQ. That

²Of course, it is not the case that every piece of knowledge statable in KEE taxonomies and PCL hierarchies has a correlate in the axiomatizable subset of KREME. We do not guarantee that there will be English expressions corresponding to anything falling outside of the axiomatizable subset.

is, we recommend using IRACQ for the diverse, complex patterns of syntax and semantics arising from verbs by providing examples of the verbs' usage, while using KNACQ for efficient acquisition of the more regular noun phrase information (excluding verb-based constructions).

1.3 KNACQ Functionality

Five cases are currently handled: one associated with concepts (or frames), two associated with binary relations (or slots), and two for adjectives. In each case, one selects a concept or binary relation (e.g., using the KREME browser) to provide lexicalizations for that domain entity.

1.3.1 Concepts and Classes

The association of English descriptions with concepts is the simplest case. It is fundamental knowledge about unmodified head nouns or frozen nominal compounds from which we can build more powerful examples. KNACQ must acquire one or more phrases for a given class, and their declension, if irregular. For the concept CARRIER of Figure 3, we provide KNACQ with the phrases *carrier* and *aircraft carrier*, which can be treated as a frozen nominal compound. Since both are declined regularly, no further information is required.

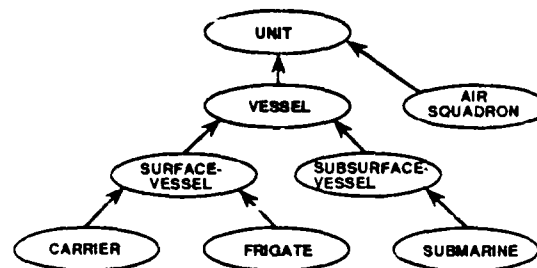


Figure 3: Simple Class Hierarchy

One can provide *surface vessel* for SURFACE-VESSEL in Figure 3, but that would not allow compositions, such as *Count the surface and subsurface vessels*. Rather, one should define *surface* and *subsurface* as non-comparative adjectives (Section 3.4) modifying phrases corresponding to VESSEL in order to define phrases for the concepts SURFACE-VESSEL and SUBSURFACE-VESSEL.

1.3.2 Attributes

Attributes are binary relations on classes that can be phrased as the *<relation> of a <class>*. For instance, suppose CURRENT-SPEED is a binary relation relating vessels to SPEED, a subclass of MEASUREMENT. An attribute treatment is the most appropriate, for *the speed of a vessel* makes perfect sense. KNACQ asks the user for one or more English phrases associated with this functional role; the user response in this case is *speed*. That answer is sufficient to enable the system to understand the kernel noun-phrases listed in Figure 4. Since ONE-D-MEASUREMENT is the range of the relation, the software knows that statistical operations such as average and maximum apply to speed.

KERNEL NOUN PHRASES

the speed of a vessel *the vessel's speed*
 the vessel speed

COMPOSITIONALLY WITH LEXICAL SEMANTICS, SYNTACTIC RULES, AND SEMANTIC RULES

The vessel speed of Vinson *Vinson has speed 1*
Carriers with speed 20 knots *Their average speeds*
The vessel's speed is 5 knots *Its speed*
Vinson has speed 20 knots *Their greatest speed*
Which vessels have speeds
Fisenhower has Vinson's speed
The carriers with speed above 20 knots
The vessels with a speed of 20 knots
Vinson has speed less than 20 knots
Which vessels have speed above 20 knots

Figure 4

The lexical information inferred is used compositionally with the syntactic rules, domain independent semantic rules, and other lexical semantic rules. Therefore, the generative capacity of the lexical semantic and syntactic information is linguistically very great, as one would require. A small subset of the examples illustrating this without introducing new domain specific lexical items

appears in Figure 4. It is this compositionality and the domain independent rules that provide the utility of KNACQ.

1.3.3 Caseframe Rules

Some lexicalizations of roles do not fall within the attribute category. For these, a more general class of regularities is captured by the notion of caseframe rules. Suppose we have a role UNIT-OF, relating CASUALTY-REPORT and MIL-UNIT. KNACQ asks the user which subset of the following six patterns in Figure 5 are appropriate plus the prepositions appropriate.

1. <CASUALTY-REPORT> is <PREP> <MIL-UNIT>
2. <CASUALTY-REPORT> <PREP> <MIL-UNIT>
3. <MIL-UNIT> <CASUALTY-REPORT>
4. <MIL-UNIT> is <PREP> <CASUALTY-REPORT>
5. <MIL-UNIT> <PREP> <CASUALTY-REPORT>
6. <CASUALTY-REPORT> <MIL-UNIT>

Figure 5: Patterns for the Caseframe Rules

For this example, the user would select patterns (1), (2), and (3) and select *for*, *on*, and *of* as prepositions. Normally, if pattern (1) is valid, pattern (2) will be as well and vice versa. Similarly, if pattern (4) is valid, pattern (5) will normally be also. As a result, the menu items are coupled by default (selecting (1) automatically selects (2) and vice versa), but this default may be simply overridden by selecting either and then deselecting the other. The most frequent examples where one does not have the coupling of those patterns is the preposition *of*.

1.3.4 Adjectives

1.3.4.1 Gradable Adjectives

Certain attribute roles have ranges that may be compared, e.g., numbers or measurements. Adjectives can be given for these roles; assume *fast* is given by the user for the CURRENT-SPEED role discussed earlier. KNACQ can correctly predict the comparative and superlative forms of *fast*. Suppose *x* and *y* are instances of vessel. The next information needed is whether *x is faster than y* means *x's speed is greater than y's speed* or *x's speed is less than y's speed*. Optionally, a threshold *t* can be given such that *x's speed is greater than t* means *x is fast*.

Additionally, one can specify antonyms for *fast*, such as *slow*. The information above would enable understanding the expressions in Figure 6.

Is Frederick faster than every carrier?
Which vessels are slower than 20 knots?
How fast are the carriers?
Show the fastest vessel.
Is Vinson fast?
Is Vinson as fast as Frederick?
How fast is the fastest carrier?

Figure 6: Examples after Defining Fast

1.3.4.2 Non-gradable Adjectives

Of the remaining types of adjectives, some correspond to refining a concept to another named concept in the hierarchy. For instance, *surface* and *subsurface* have that property given the network in Figure 3. In such a case, one must indicate the general concept, the refined concept, the adjective, and any synonyms.

Others correspond to an arbitrary restriction on a concept having no explicit refined concept in the domain model. Though one could add such a refined concept to the hierarchy, we allow the user to state a logical form to define the adjective as a predicate of one argument.

A case that we have not covered in KNACQ is non-gradable adjectives that are predicates of more than one argument. An example in the FCCBMP domain is mission readiness ratings, *M1*, *M2*, *M3*, *M4*, and *M5*. These occur in expressions such as *Enterprise is M2 on anti-air warfare*, where both the vessel and the type of mission are arguments.

1.4 Experience Thus Far

There are several things we have learned even in the early stages of KNACQ's development based on porting Janus to CASES, an expert system in DARPA's Fleet Command Center Battle Management Program (FCCBMP). In this use of KNACQ, the original domain model pertinent to the portion requiring a natural language interface consisted of 189 concepts and 398 roles.

First, no restructuring of that domain model was necessary, nor was any deletion required.

Second, we found it useful to define some additional concepts and roles. Certain subclasses not critical to the expert system were nevertheless lexically significant. In total, only 123 concepts were added: 53 for classes that were treated as strings in the expert system and 70 domain-independent concepts pertaining to time, space, events, commands, etc. Similarly, 28 roles were added: 24 domain-independent roles and 4 domain-specific roles. In addition, some roles were added to represent role chains that are lexically significant directly. For instance, the DISPLACEMENT of the VESSEL-CLASS of a VESSEL is lexicalizable as *the vessel's displacement*. Starting from a given concept, a procedure exists to run through a subhierarchy checking for role chains of length two to ask the user if any of those are significant enough to have lexical forms. For the example network we needed to add only 5 roles for this purpose.

Third, 1093 proper nouns (e.g., ship and port names) were inferred automatically from the instances in the expert system taxonomy.

As a result, the time required to supply lexical syntax and semantics was much less than we had experienced before developing KNACQ. In two days we were able to provide 563 lexical entries (root forms not counting morphological variants) for 103 concepts and 353 roles. Together with the automatically inferred proper nouns, this was approximately 91% of the domain-dependent vocabulary used for the demonstration. That is about 5-10 times more productivity than we had experienced before with manual means.

1.5 Related Work

TEAM [5] is most directly related, having many similar goals, though focussed on data bases rather than expert systems. The novel aspects of KNACQ by contrast with TEAM are (1) accepting an expert system domain model as input (KNACQ) contrasted with the mathematically precise semantics of a relational data base (TEAM) and (2) how little linguistic information is required of the KNACQ user.

A complementary facility is provided in TELI [3] and in LIFER [6]. KNACQ is meant to be used by the (expert system's) knowledge engineer, who understands the expert system domain model, to

define a large portion of the vocabulary, that portion corresponding to simple noun phrase constructions for each concept and role: one uses KNACQ to bootstrap the initially empty domain-dependent lexicon. TELI and LIFER, on the other hand, are meant to let the end user define additional vocabulary in terms of previously defined vocabulary, e.g., *A ship is a vessel*; therefore, those systems assume an extensive vocabulary provided by the system builder. Obviously, providing both kinds of capabilities is highly desirable.

1.6 Conclusions

KNACQ is based on the goal of allowing very rapid, inexpensive definition of a large percentage of the vocabulary necessary in a natural language interface to an expert system. It provides the knowledge engineer with the facilities to browse his/her taxonomic knowledge base, and to state head nouns, nominal compounds, and their non-clausal modifiers for referring to the concepts and roles in the knowledge base. Given that, KNACQ infers the necessary lexical syntactic and lexical semantic knowledge. Furthermore, if appropriate instances in the expert system knowledge base already have names, KNACQ will add proper nouns for those instances to the lexicon.

KNACQ does not cover the inference of complex constructions typical of verbs and their nominalizations. IRACQ [2] allows a user to enter examples of usage for acquiring lexical syntax and semantics for complex constructions.

Our experience thus far is that KNACQ has achieved our goals of dramatically reducing the time it takes to define the vocabulary for an expert system interface. It appears to have increased our own productivity several fold. (However, KNACQ has not yet been provided to a knowledge engineer with no knowledge of computational linguistics.)

We believe that the problem of linguistic knowledge acquisition is critical not just as a practical issue regarding widespread availability of natural language interfaces. As our science, technology, and systems become more and more mature, the ante to show progress could involve more and more effort in filling domain-specific knowledge bases. The less effort spent on such knowledge bases, the more effort can be devoted to unsolved problems.

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2. Discourse Entities in Janus

Damaris M. Ayuso³

Abstract

This paper addresses issues that arose in applying the model for discourse entity (DE) generation in B. Webber's work (1978, 1983) to an interactive multi-modal interface. Her treatment was extended in 4 areas: (1) the notion of context dependence of DEs was formalized in an intensional logic, (2) the treatment of DEs for indefinite NPs was modified to use skolem functions, (3) the treatment of dependent quantifiers was generalized, and (4) DEs originating from non-linguistic sources, such as pointing actions, were taken into account. The discourse entities are used in intra- and extra-sentential pronoun resolution in BBN Janus.

2.1 Introduction

Discourse entities (DEs) are descriptions of objects, groups of objects, events, etc. from the real world or from hypothesized or possible worlds that are evoked in a discourse. Any communicative act, be it spoken, written, gestured, or system-initiated, can give rise to DEs. As a discourse progresses, an adequate discourse model must represent the relevant entities, and the relationships between them [4]. A speaker may then felicitously refer anaphorically to an object (subject to focusing or centering constraints (Grosz et al., 1983, Sidner 1981, 1983, Brennan et al. 1987)) if there is an existing DE representing it, or if a corresponding DE may be directly inferred from an existing DE. For example, the utterance "Every senior in Milford High School has a car" gives rise to at least 3 entities, describable in English as "the seniors in Milford High School", "Milford High School", and "the set of cars each of which is owned

by some senior in Milford High School". These entities may then be accessed by the following next utterances, respectively:

"They graduate in June."

"It's a good school."

"They completely fill the parking lot."

Webber (1978, 1983) addressed the question of determining what discourse entities are introduced by a text. She defined rules which produce "initial descriptions" (IDs) of new entities stemming from noun phrases, given a meaning representation of a text. An ID is a logical expression that denotes the corresponding object and uses only information from the text's meaning representation. The declarative nature of Webber's rules and the fact that they relied solely on the structure of the meaning representation, made her approach well suited for implementation.

The present work recasts her rules in Janus's intensional logic framework (described in section 2.2). Two goals guided our approach: (1) that our DE representations be semantically clear and correct according to the formal definitions of our language, and (2) that these representations be amenable to the processing required in an interactive environment such as ours, where each reference needs to be fully resolved against the current context.

In the following sections, we first present the representational requirements for this approach, and introduce our logical language (section 2.2).

Then we discuss issues that arose in trying to formalize the logical representation of DEs with respect to (1) the context dependence of their denotations, and (2) the indeterminacy of denotation that arises with indefinite NPs. For context dependence, we use an intensional logic expression indexed by time and world indices (discussed in section 2.3). This required us to extend Webber's rules to detect modal and other index-binding contexts. In representing

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DEs for indefinites (appearing as existential formulae in our meaning representation), we replaced Webber's EVOKE predicate with skolem constants for the independent case, where it does not contain a variable bound by a higher FORALL quantifier (section 2.4), and do not use EVOKE at all in the dependent case.

In section 2.5 we introduce a generalized version of the rules for generating DEs for dependent quantifiers stemming from indefinite and definite NPs which overcomes some difficulties in capturing dependencies between discourse entities.

In our multi-modal interface environment, it is important to represent the information on the computer screen as part of the discourse context, and allow references to screen entities that are not explicitly introduced via the text input. Section 2.6 briefly discusses some of these issues and shows how pointing actions are handled in Janus by generating appropriate discourse entities that are then used like other DEs.

Finally, section 2.7 concludes and presents plans for future work.

This is, to our knowledge, the first implementation of Webber's DE generation ideas. We designed the algorithms and structures necessary to generate discourse entities from our logical representation of the meaning of utterances, and from pointing gestures, and currently use them in Janus's [22, 1] pronoun resolution component, which applies centering techniques (Grosz et al., 1983, Sidner 1981, 1983, Brennan et al. 1987) to track and constrain references. Janus has been demonstrated in the Navy domain for DARPA's Fleet Command Center Battle Management Program (FCCBMP), and in the Army domain for the Air Land Battle Management Program (ALBM).

2.2 Meaning Representation for DE Generation

Webber found that appropriate discourse entities could be generated from the meaning representation of a sentence by applying rules to the representation that are strictly structural in nature, as long as the representation reflects certain crucial aspects of the sentence. This has the attractive feature that any syntactic formalism may be used if an appropriate semantic representation is produced. Some of the

requirements (described in (Webber 1978, 1983)) on the representation are: (1) it must distinguish between definite and indefinite NPs and between singular and plural NPs, (2) it must specify quantifier scope, (3) it must distinguish between distributive and collective readings, (4) it must have resolved elided verb phrases, and (5) it must reflect the modifier structure of the NPs (e.g., via restricted quantification). An important implied constraint is that the representation must show one recognizable construct (a quantifier, for example) per DE-invoking noun phrase. These constructs are what trigger the DE generation rules.

Insofar as a semantic representation reflects all of the above in its structure, structural rules will suffice for generating appropriate DEs, but otherwise information from syntax or other sources may be necessary. There is a trade-off between using a level of representation that shows the required distinctions, and the need to stay relatively close to the English structure in order to only generate DEs that are justified by the text. For example, in Janus, in addition to quantifiers from NPs, the semantic representation has quantifiers for verbs (events), and possibly extra quantifiers introduced in representing deeper meaning or by the collective/distributive processing. Therefore, we check the syntactic source of the quantifiers to ensure that we only generate entities for quantifiers that arose from NPs (using the bound variable as an index into the parse tree).

Other than the caveat just discussed, the Janus meaning representation language WML (for World Model Language) [6] meets all the other constraints for DE generation. WML is a higher-order intensional language that is based on a synthesis between the kind of language used in PHLIQA [12] and Montague's Intensional Logic [11]. A newer version of WML [16] is used in the BBN Spoken Language System [2]. The intensionality of WML makes it more powerful than the sample language Webber used in developing her structural rules.

The scoping expressions in WML have a sort field (which restricts the range of the variable) and have the form:

$$(B \ x \ S \ (P \ x))$$

where **B** is a quantifier such as FORALL or EXISTS, a term-forming operator like IOTA or SET, or the lambda abstraction operator LAMBDA. **S** is the sort, a set-denoting expression of arbitrary complexity specifying the range of *x*, and **(P x)** is a predication in terms of *x*. The formal semantics of WML assigns a type to each well-formed expression which is a function of the types of its parts. If expression *E* has type

T, the denotation of E, given a model M and a time *t* and world *w*, is a member of the set which is T's domain. One use of types in our system is for enforcing selectional restrictions. The formation rules of WML, its type system, and its recursive denotation definition provide a formal syntax and semantics for WML.

2.3 Context Dependence of Discourse Entities

A formal semantics was assumed though not given for the sample logical language used by Webber. The initial descriptions (IDs) of DEs produced by her rules were stated in this language too, and thus are meant to denote the object the DE represents. For example, the rule which applies to the representation for independent definite NPs assigns to the resulting DE an ID which is the representation itself:

```
(t x S (P x)) =>
  ID: (t x S (P x))
```

where *t* is Russell's iota operator. Thus, the ID for "the cat" in "I saw the cat" is (*t* x cats T). (Since the body of the *t* in this example has no additional predication on *x*, it is merely T, for TRUE.) However, because IDs are solely drawn from the meaning representation of the isolated text, they may not suffice to denote a unique object. Connection to prior discourse knowledge or information from further discourse may be necessary to establish a unique referent, or determining the referent may not even be necessary. For example, the ID for "the cat" would need to be evaluated in a context where there is only one salient cat in order to obtain a denotation.

Our system's representation of a DE is a structure containing several fields. The "logical-form" field contains a WML expression which denotes the object the DE describes (this corresponds roughly to Webber's ID). Given that WML is intensional, we are able to explicitly represent context dependence by having the logical form include an intensional core, plus tense, time, and world information (which includes discourse context) that grounds the intension so that it may be evaluated. For example, the logical form for the DE corresponding to "the cat" in our system is

```
((INTENSION (IOTA x cats T))
  time world)
```

where *time*, if unfilled, defaults to the present, and

world defaults to the real world and current discourse state. The semantics of our IOTA operator makes it denotationless if there is not exactly one salient object that fits the description in the context, else its denotation is that unique object. In our interactive system each reference needs to be fully resolved to be used successfully. If unknown information is necessary to obtain a *unique* denotation for a IOTA term, a simple clarification dialogue should ensue. (Clarification is not implemented yet, currently the set of all values fitting the IOTA is used.)

An example using the time index is the noun phrase "the ships that were combat ready on 12/1/88", which would generate a DE with logical form:

```
((INTENSION
  (PAST (INTENSION
    (IOTA x (SETS ships)
      (COMBAT-READY x))))
  12/1/88 world)
```

Representing this time index in the logical form is crucial, since a later reference to it, made in a different time context must still denote the original object. For example, "Are they deployed?" must have "they" refer to the ships that were combat ready on 12/1/88, not at the time of the latter utterance.

In order to derive the proper time and world context for the discourse entities, we added structural rules that recognize intensional and index-binding logical contexts. Our DE generation algorithm uses these rules to gather the necessary information as it recurses into the logical representation (applying rules as it goes) so that when a regular rule fires on a language construct, the appropriate outer-scoping time/world bindings will get used for the generated DEs.

It should be noted that, as the discussion above suggests, a definite NP always gives rise to a new discourse entity in our system. If it is determined to be anaphoric, then a pointer to the DE it co-refers with (when found) will be added to its "refers-to" field, indicating they both denote the same object.

2.4 DEs for Independent Indefinite NPs

In Webber's work, the initial description (ID) for a DE stemming from an independent existential (i.e., with no dependencies on an outer FORALL quantifier), contained an EVOKE predicate. "I saw a cat":

```
(EXISTS x cats (saw I x))
```

would generate a DE with ID:

```
(1 x cats
  (& (sa I x)
    (EVOKE Sent x)))
```

"The cat I saw that was evoked by sentence Sent", where Sent is the parsed clause for "I saw a cat". The purpose of EVOKE was to make clear that although more than one cat may have been seen, the "a" picks out one in particular (which one we do not know except that it is the one mentioned in the utterance), and this is the cat which makes the EVOKE true. Any subsequent reference then picks out the same cat because it will access this DE. The semantics of the EVOKE predicate and the type of the S argument (which is syntactic in nature) were unclear, so we looked for a different formulation with better understood semantics.

Predicate logic already provides us with a mechanism for selecting arbitrary individuals from the domain via skolem functions (used as a mechanism for removing existentials from a formula while preserving satisfiability). Skolem functions have been used in computational linguistics to indicate quantifier scope, for example [17]. Following a suggestion by R. Scha, we use skolem functions in the logical form of the DE for the "indefinite individuals" introduced by independent existentials [13]. For clarity and consistency with the rest of the language, we use a *sorted* skolem form, where the range of the function is specified. Since we use this for representing existentials that are independent, the function has no arguments and is thus equivalent to a sorted constant whose denotation is undetermined when introduced. (In this sense it is consistent with Karttunen's (1976) and Kamp's (1984) view of the indefinite's role as a referential constant, but unlike Kamp, here the sentence's meaning representation is separate from the representation of the evoked entity.)

Thus we introduced a new operator to WML named SKOLEM, for expressions of the form (SKOLEM *n* <sort>), where *n* is an integer that gets

incremented for each new skolem created, as a way of naming the skolem function. For the example above, the core logical form (stripping the outer intension and indices) for the DE of "a cat" would be:

```
(SKOLEM 1
  (SET x cats (saw I x)))
```

denoting a particular cat from the set of all the cats I saw. The type of a SKOLEM expression is well-defined and is given by the following type rule:

```
TYPEOF (SKOLEM INTEGERS
  (SETS a))
= a
```

where INTEGERS is the type for integers, and (SETS *a*) is the type of sets whose members have type *a*. This type rule says that when the first argument of SKOLEM is of type INTEGER, and the second is a set with elements of type *a*, then the type of the SKOLEM expression is *a*. Therefore, the type of the above example is *cats*. The explicit connection to the originating sentence which the EVOKE predicate provided is found in our scheme outside of the logical representation by having a pointer in the DE's structure to the parse tree NP constituent, and to the structure representing the communicative act performed by the utterance (in the fields "corresponding-constituent" and "originating-communicative-act", respectively). These connections are used by the pronoun resolution algorithms which make use of syntactic information.

Does the denotation of a skolem constant ever get determined? In narrative, and even in conversation, identifying the individual referred to by the indefinite NP frequently doesn't occur. However, in our interactive system, each reference must be fully resolved. When the evaluation component of Janus determines a successful value to use for the existential in the text's logical form, the appropriate function denotation for SKOLEM *n* gets defined, and the "extension" field is set for the discourse entity.

Note that many interesting issues come up in the treatment of reference to these indefinite entities in a real system. For example, cooperative responses by the system introduce new entities that must be taken into account. If the user asks "Is there a carrier within 50 miles of Hawaii?", a cooperative "There are two: Constellation and Kennedy" (as opposed to just "Yes") must add those two carriers as entities, which now overshadow the singular skolem entity for "a carrier within 50 miles of Hawaii". On the other hand, a "No" answer should block any further reference to the carrier skolem, since its denotation is null, while still allowing a reference to a class entity derived from it, as in "Is there *one* near San Diego?" where *one* refers to the class *carriers*.

The treatment presented works for straightforward cases of independent indefinites. Trickier cases like donkey sentences [8, 19] and interactions with negation have not yet been addressed.

2.5 Dependent NPs

2.5.1 Dependent Indefinite NPs

Our work uncovered a need for modifications in Webber's structural rules for quantifiers from indefinite and definite NPs which have dependencies on variables bound directly or indirectly by an outer FORALL quantifier. In this section we address the case of dependent existentials arising from indefinite NPs. We first argue that the predicate EVOKE is not needed in this context. Then we point out the need for generalizing the rule to take into account not just FORALL, but all scoping operators that intervene between the outer FORALL and the inner EXISTS. Finally, we show that the dependencies between discourse entities must be explicitly maintained in the logical forms of newly created DEs that depend on them.

Webber's rules are designed to apply from the outermost quantifier in; each time a rule is applied the remaining logical form is modified to be in terms of the just created DE. For example, "Every boy saw a girl he knows" has logical form (for the bound pronoun reading):

```
(FORALL x boys
  (EXISTS y (SET y' girls
    (knows x y'))
    (saw x y)))
```

The first step is to apply the rule for an independent universal quantifier:

```
R0:
  (FORALL x S (P x)) => de: S]
```

This application yields the entity for "the set of all boys"

DE₁: boys

and we rewrite the logical form to be:

```
(FORALL x DE1
  (EXISTS y (SET y' girls
    (knows x y'))
    (saw x y)))
```

The steps shown so far are consistent with both Webber's and our approach. Now we want to apply the general rule for existentials within the body of a distributive, in order to generate an entity for the relevant set of girls. Webber uses Rule 3 in [20] (here corrected to position the existential's sort S inside the scope of the outer quantifiers in the generated DE):

```
R3: (FORALL y1...yk
      (EXISTS x S (P x))) =>
  de: (SET x things
      (EXISTS y1...yk
        (& (member x S) (P x)
          (EVOKE Sent x))))
```

where FORALL y₁...y_k is shorthand for FORALL y₁ de₁ (...FORALL y_k de_k, analogously for EXISTS, and S or P depends directly or indirectly on y₁...y_k.

Now the first DE we want to generate with this rule is for "the set of girls, each of which is known by some boy in DE₁, and was seen by him". Does each girl in the set also have to satisfy an EVOKE predicate? It seems that any future reference back to the set formed by the existential seeks to obtain *all* items fitting the description, not some subset constrained by EVOKE. For example, if the example above is followed by "the girls tried to hide", taking "the girls" anaphorically, one wants *all* the girls seen by some boy in DE₁ that knows them, no less. Our core logical representation for the set of girls is thus:

```
DE2: (SET y girls
      (EXISTS x DE1
        (& (knows x y)
          (saw x y))))
```

So the modified rule used in producing DE₂ is:

```
R3': (FORALL y1...yk
      (EXISTS x S (P x))) =>
  de: (SET x St
      (EXISTS y1...yk
        (& (member x S)
          (P x))))
```

where EVOKE has been removed, and the DE's sort field is S_t for the "root type" of S, which is the type of the members of S, in order to appropriately constrain the DE's sort (instead of leaving it as the unconstrained "things").

A second change that needs to be made is to generalize the left hand side of the rule so that the scoping expressions outscoping the inner EXISTS in the pattern also be allowed to include other scoping operators, such as EXISTS and IOTA. As long as the

outermost quantifier is a FORALL, any other dependent scoping expression within it will generate a set-denoting DE and will behave as a distributive environment as far as any more deeply embedded expressions are concerned. In other words, the distributiveness chains along the dependent quantifiers. To see this, consider the more embedded example "Every boy gave a girl he knew a peach she wanted", where there is an intervening existential between the outer FORALL and innermost EXISTS. The core logical form for this sentence is:

```
(FORALL x boys
  (EXISTS y (SET y' girls
    (knows x y'))
    (EXISTS z (SET z' peaches
      (wants y z'))
      (gave x y z))))
```

DE₁ would be as above. Using rule R3' DE₂ becomes:

```
DE2:
  (SET y girls
    (EXISTS x DE1
      (& (knows x y)
        (EXISTS z (SET z' peaches
          (wants y z'))
          (gave x y z))))))
```

"The set of girls, each of which is known by some boy in DE₁, and got a peach she wanted from that boy." Now the peach quantifier should generate a set DE in terms of DE₁ and DE₂. Applying R3' gives us:

```
DE3:
  (SET z peaches
    (EXISTS x DE1
      (EXISTS y DE2
        (& (wants y z)
          (gave x y z))))))
```

"The set of peaches z such that there is a girl in DE₂ (who is known by some boy in DE₁, and who got some peach she wanted from the boy), who wants z, and who got it from some boy in DE₁".

Now a third and final problem becomes apparent: for the general case of arbitrary embedding of dependent quantifiers we generate a DE (e.g., DE₃) dependent on other DEs from the outer quantifiers, but the dependencies between those DEs (e.g., DE₁ and DE₂) are not maintained. This is counter-intuitive, and also leads to an under-specified set DE. In the peaches example above, envision the situation where a boy b_1 gave out two peaches p_1 and p_2 : one to a girl g_1 he knew, and one to a girl g_2 he didn't know.

who also got a peach p_3 from another boy b_2 who *did* know her. These are the facts of interest in this scenario:

1. (& (gave $b_1 g_1 p_1$) (know $b_1 g_1$)
(wants $g_1 p_1$))
2. (& (gave $b_1 g_2 p_2$)
(NOT (know $b_1 g_2$))
(wants $g_2 p_2$))
3. (& (gave $b_2 g_2 p_3$) (know $b_2 g_2$)
(wants $g_2 p_3$))

Since b_1 and b_2 are in DE₁ (due to facts 1 and 3), and g_2 is in DE₂ (due to fact 3), then p_2 is in DE₃ (due to fact 2 and according to the DE₃ logical form above). But p_2 should not be in DE₃, since p_2 was NOT given to a girl by a boy she knew. The set of peaches obtained for DE₃ is too large. The problem would not arise if in the DE₃ logical form, the variables ranging over DE₂ were appropriately connected to DE₁ using the dependent restriction present in the original formula (knows x y). A correct DE₃ is:

```
DE3:
  (SET z peaches
    (EXISTS x DE1
      (EXISTS y (SET y' DE2
        (knows x y'))
        (& (wants y z)
          (gave x y z))))))
```

To be able to do this, the rule-application algorithm must be modified to include the restriction information (for dependent restrictions) when the formula gets rewritten in terms of a newly created DE. Therefore the final generalized rule, which includes other scoping operators and works on properly connected DEs is as follows:

```
R3'':
  (FORALL v1 S1
    (Q2 v2 S2 ... Qn vn Sn
      (EXISTS x S (P x)))) =>
  de: (SET x St
    (EXISTS v1 S1 ... vn Sn
      (& (member x S)
        (P x))))
```

where S or P depend directly or indirectly on $v_1 \dots v_n$, Q_i may be FORALL, EXISTS, or IOTA, and the scoping operators outside the inner EXISTS have already been processed by any appropriate rules that have replaced their original sorts by the S_i s, which are in terms of generated DEs and explicitly show any DE dependencies. The right hand side is as before, with existentials picking out elements from each outer quantifier.

2.5.2 Dependent Definite NPs

Some of the problems described in the previous section also arise for the rule to handle dependent definite NPs. Definite NPs are treated as IOTA terms in WML. (Webber's logical language in [18] used a similar ι . The treatment was later changed [20] to use the definite existential quantifier "Exists!", but this difference is not relevant for the following.) Replacing IOTA for ι in Webber's (1978) rule 5:

```
R5: (FORALL  $y_1 \dots y_k$ 
      (P (IOTA  $x$  S (R  $x$ )))) =>
  de: (SET  $z$  things
       (EXISTS  $y_1 \dots y_k$ 
        (=  $z$ 
         (IOTA  $x$  S (R  $x$ ))))))
```

where $y_1 \dots y_k$ are universal quantifiers over DEs as in R3 above, and S or R depend directly or indirectly on $y_1 \dots y_k$.

The second and third extensions discussed in the previous section are needed here too: generalizing the quantifiers that outscope the inner existential, and keeping the dependencies among the DEs explicit to avoid under-specified sets. An example of an under-specified set arises when the dependent IOTA depends jointly on more than one outer variable: for example, in "Every boy gave a girl he knew *the* peach *they* selected", each peach depends on the selection by a boy and a girl together. Take a scenario analogous to that in the previous section, with the facts now as follows (replacing "selected" for "wants"):

1. (& (gave $b_1 g_1 p_1$) (know $b_1 g_1$)
 (selected
 (SETOF $b_1 g_1$) p_1))
2. (& (gave $b_1 g_2 p_2$)
 (NOT (know $b_1 g_2$))
 (selected
 (SETOF $b_1 g_2$) p_2))
3. (& (gave $b_2 g_2 p_3$) (know $b_2 g_2$)
 (selected
 (SETOF $b_2 g_2$) p_3))

By an analogous argument as before, using R5, the set of peaches will incorrectly contain p_2 , given by a boy to a girl who selected it with him, but whom he did not know. The modified rule is analogous to R3" in the previous section:

```
R5' :
  (FORALL  $v_1 S_1$ 
    ( $Q_2 v_2 S_2 \dots Q_n v_n S_n$ 
      (P (IOTA  $x$  S (R  $x$ )))))) =>
  de: (SET  $z$   $S_z$ 
       (EXISTS  $v_1 S_1 \dots v_n S_n$ 
        (=  $z$ 
         (IOTA  $x$  S (R  $x$ ))))))
```

Note that this problem of under-specified sets does not arise when the dependency inside the IOTA is on one variable, because the definite "the" forces a one-to-one mapping from the possible assignments of the single outer variable represented in the IOTA to the IOTA denotations. If we use the example, "Every boy gave a girl he knew *the* peach she wanted", with logical form:

```
(FORALL  $x$  boys
  (EXISTS  $y$  (SET  $y'$  girls
    (knows  $x y'$ ))
    (gave  $x y$  (IOTA  $z$  peaches
      (wants  $y z$ ))))))
```

there is such a mapping between the set of girls in the appropriate DE_2 (those who got the peach they wanted from a boy they knew) and the peaches in DE_3 obtained via R5' (the peaches that some girl in DE_2 wanted). Each girl wants exactly one peach, so facts 2 and 3, where the same girl receives two different peaches, cannot occur. So the definite ensures that no scenario can be constructed containing extra items, as long as there is only one outer variable in the inner iota. However in the joint dependency example above using "selected", the one-to-one mapping is between boy-girl *pairs* and peaches, so the relationship between the boys and the girls becomes an integral part of determining the correct DE_3 .

2.6 Non-Linguistic Discourse Entities

In a dialogue between persons, references can be made not only to linguistically-introduced objects, but also to objects (or events, etc.) that become salient in the environment through some non-linguistic means. For example, a loud noise may prompt a question "What was *that*?", or one may look at or point to an object and refer to it, "What's wrong with *it*?" It seems an attention-drawing event normally precedes such a reference.

In the Janus human-computer environment, non-linguistic attention-drawing mechanisms that we have identified so far include pointing actions by the user, and highlighting (by the system) of changes on the screen as a response to a request (or for other reasons). The appearance of answers to questions also draws the user's attention. We incorporated these into generalized notion of a "communicative act" which may be linguistic in nature (English input or generated English output), a pointing gesture by the user, or some other system-initiated action. Any communicative act may give rise to DEs and affect the focused entities in the discourse.

We have implemented procedures to handle pointing actions by generating discourse entities which are then used in the pronoun resolution component uniformly with the others. For example, after the request "Show me the C1 carriers in the Indian Ocean" the system will display icons on the color monitor representing the carriers. The user can then say "Which of them are within 200 miles of it? <point with mouse to Kennedy>". Before the sentence gets processed, a discourse entity with the logical form (IOTA x carriers (nameof x "Kennedy")) will be created and added to the list of entities currently in focus (the "forward looking centers" of the last linguistic act); the DE's "originating-communicative-act" field will point to a newly created "pointing" communicative act. Since "them" and "it" have different number requirements, there is no ambiguity and the anaphor resolution module resolves "them" to the DE corresponding to "the C1 carriers in the Indian Ocean" and "it" to the DE for Kennedy. We are currently working on having system-initiated actions also generate entities.

2.7 Conclusions and Further Work

Webber's general approach to discourse entity generation from a logical representation proved very useful in our efforts. We were able to recast her basic ideas in our logical framework, and currently use the generated DEs extensively.

The fact that the generation of DEs is done via structural rules operating on a semantic representation provided a degree of modularity that allowed our pronoun resolution component to work *automatically* when we combined a new syntactic component with our semantic and discourse component (replacing an ATN by a unification grammar, in an independently motivated experiment). We are currently starting to port the DE generation component to the BBN Spoken Language System [2], and plan to integrate it with the intra-sentential mechanisms in [7]. The fact that entity representations are mostly semantic in nature, not syntactic, also facilitated the addition and use of non-linguistic entities in a *uniform way*.

There are several areas that we would like to study to extend our current treatment. We want to address the interactions between centering phenomena and non-linguistic events that affect discourse focus, such as changing contexts via a menu selection in an expert system.

Our paraphrasing component [10] already uses the discourse entities to a limited extent. One area of future work is to have the language generator make more extensive use of them, so it can smoothly refer to focused objects.

Finally, although quantified expressions are already generated in Janus for events implicit in many verbs, they are not being used for DEs. We would like to address the problem of event reference and its interaction with temporal information, using ideas such as those in [21] and in the special issue of *Computational Linguistics* on tense and aspect (Vol. 14, Number 2 June 1988).

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3. A Metaplan Model for Problem-Solving Discourse

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ABSTRACT

The structure of problem-solving discourse in the expert advising setting can be modeled by adding a layer of metaplans to a plan-based model of the task domain. Classes of metaplans are introduced to model both the agent's gradual refinement and instantiation of a domain plan for a task and the space of possible queries about preconditions or fillers for open variable slots that can be motivated by the exploration of particular classes of domain plans. This metaplan structure can be used to track an agent's problem-solving progress and to predict at each point likely follow-on queries based on related domain plans. The model is implemented in the Pragma system where it is used to suggest corrections for ill-formed input.

3.1 Introduction

Significant progress has been achieved recently in natural language (NL) understanding systems through the use of plan recognition and "plan tracking" schemes that maintain models of the agent's domain plans and goals. Such systems have been used for recognizing discourse structure, processing anaphora, providing cooperative responses, and interpreting intersentential ellipsis. However, a model of the discourse context must capture more than just the plan structure of the problem domain. Each discourse setting, whether argument, narrative, cooperative planning, or the like, involves a level of organization more abstract than that of domain plans, a level with its own structures and typical strategies. Enriching the domain plan model with a model of the agent's

plans and strategies on this more abstract level can add significant power to an NL system. This paper presents an approach to pragmatic modeling in which metaplans are used to model that level of discourse structure for problem-solving discourse of the sort arising in NL interfaces to expert systems or databases.

The discourse setting modeled by metaplans in this work is expert-assisted problem-solving. Note that the agent's current task in this context is creating a plan for achieving the domain goal, rather than executing that plan. In problem-solving discourse, the agent poses queries to the expert to gather information in order to select a plan from among the various possible plans. Meanwhile, in order to respond to the queries cooperatively, the expert must maintain a model of the plan being considered by the agent. Thus the expert is in the position of deducing from the queries that are the agent's observable behavior which possible plans the agent is currently considering. The metaplans presented here model both the agent's plan-building choices refining the plan and instantiating its variables and also the possible queries that the agent may use to gain the information needed to make those choices. This unified model in a single formalism of the connection between the agent's plan-building choices and the queries motivated thereby allows for more precise and efficient prediction from the queries observed of the underlying plan-building choices. The model can be used for plan tracking by searching outward each time from the previous context in a tree of metaplans to explore the space of possible plan-building moves and related queries, looking for a predicted query that matches the agent's next utterance. Thus the examples will be presented in terms of the required search paths from the previous context to find a node that matches the context of the succeeding query.

This metaplan model is discussed in two parts.

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with Section 2 covering the plan-building class of metaplans, which model the agent's addition of new branches to the domain plan tree and instantiation of variables, while Section 3 presents examples of plan feasibility and slot data query metaplans, which model the agent's strategies for gathering information to use in plan-building. Section 4 then compares this modeling approach to other plan-based styles of discourse modeling, Section 5 discusses applications for the approach and the current implementation, and Section 6 points out other classes of metaplans that could be used to broaden the coverage of the model and other areas for further work.

3.2 Plan Building Metaplans

In this approach, the plan-building metaplans discussed in this section model those portions of problem-solving behavior that explore the different possible refinements of the plan being considered and the different possible variable instantiations for it. The domain for all the examples in this paper is naval operations, where the agent is assumed to be a naval officer and the expert a cooperative interface to a fleet information system. The examples assume a scenario in which a particular vessel, the Knox, has been damaged in an accident, thereby lowering its readiness and that of its group. The top-level goal is thus assumed to be restoring the readiness of that group from its current poor rating to good, expressed as (IncreaseGroupReadiness Knox-group poor good).

The domain plans in Pragma are organized in a classification hierarchy based on their effects and preconditions, so that a node in that hierarchy like the top-level instance of IncreaseGroupReadiness in the examples actually stands for the class of plans that would achieve that result in a certain class of situations. The plan class nodes in this hierarchy can thus be used to represent partially specified plans, the set of plans that an agent might be considering that achieves a particular goal using a particular strategy. The subplans (really plan subclasses) of IncreaseGroupReadiness shown in Figure 1 give an idea of the different strategies that the agent may consider for achieving this goal. (Variables are shown with a prefixed question mark.) The plan classification depends on the circumstances, so that RepairShip only functions as a subplan of IncreaseGroupReadiness when its object ship is specified as the Knox, the damaged one, but some of the plans also introduce new variables like ?new-ship, introduced

by the ReplaceShip plan, that can take on any value permitted by the plan's preconditions. Each of these plans also has its own subactions describing how it can be achieved, so that ReplaceShip, for example, involves sailing the ?new-ship to the location of the damaged ship, having it take over the duties of the damaged ship, and then sailing or towing the damaged one to a repair facility.

```
(IncreaseGroupReadiness
  Knox-group poor good)      (1)
  (RepairShip Knox)          (2)
  (ReinforceGroup Knox-group ?new-ship) (3)
  (ReplaceShip Knox ?new-ship) (4)
```

Figure 1: Subplans of IncreaseGroupReadiness

Those subactions, in turn, specify goals for which there can be multiple subplans. The metaplan structures modeling the problem-solving discourse are built on top of this tree of domain plans and actions.

3.2.1 Plan Refining Metaplans

The *build-plan* metaplan is used to capture the agent's goal of constructing a plan to achieve a particular goal, with the *build-subplan* and *build-subaction* metaplans modeling the problem-solving steps that the agent uses to explore and refine the class of domain plans for that goal. An instance of *build-subplan*, say, reflects the agent's choice of one of the possible subplan refinements of the current domain plan as the candidate plan to be further explored. For example, the initial context assuming an IncreaseGroupReadiness plan due to damage to the Knox would be represented in our model by the *build-plan* node on line (1) of Figure 2.

```
(build-plan
  (IncreaseGroupReadiness
    Knox-group poor good))      (1)
  (build-subplan
    (IncreaseGroupReadiness ...)
    (ReplaceShip ...))          (2)
  (build-plan
    (ReplaceShip Knox ?new-ship)) (3)
  (build-subaction
    (ReplaceShip ...) (Sail ...)) (4)
  (build-plan
    (Sail ?new-ship ?loc Knox-loc)) (5)
```

Figure 2: Build-Plan, Build-Subplan, and Build-Subaction

If we suppose that the agent first considers replacing Knox with some other frigate, that would be modeled

as a *build-subplan* child (2) of the *build-plan* for the *IncreaseGroupReadiness* plan (1), that would in turn generate a new *build-plan* for *ReplaceShip* (3). If the agent continues by considering how to get the new ship to that location, that would be represented as a *build-subaction* child (4) of the *build-plan* for *ReplaceShip* that expands the *Sail* action.

3.2.2 Variable Constraining Metaplans

In addition to the plan-refining choice of subplans and exploration of subactions, the other plan-building task is the instantiation of the free variables found in the plans. Such variables may either be directly instantiated to a specified value, as modeled by the *instantiate-var* metaplan, or more gradually constrained to subsets of the possible values, as modeled by *add-constraint*.

The *instantiate-var* metaplan reflects the agent's choice of a particular entity to instantiate an open variable in the current plan. For example, the *ReplaceShip* plan in Figure 2 (3) introduces a free variable for the ?new-ship. If the agent were to choose the *Roark* as a replacement vessel, that would be modeled by an *instantiate-var* metaplan attached to the *build-plan* node that first introduced the variable, as shown in Figure 3.

```
(build-plan (ReplaceShip Knox ?new-ship))      (1)
  (instantiate-var ?new-ship Roark)              (2)
    (build-plan (ReplaceShip Knox Roark))        (3)
```

Figure 3: *Instantiate-Var*

The agent may also constrain the possible values for a free variable without instantiating it by using a predicate to filter the set of possible fillers. For example, the agent might decide to consider as replacement vessels only those that are within 500 miles of the damaged one. The predicate from the *add-constraint* node in line (2) of Figure 4 is inherited by the lower *build-plan* node (3), which thus represents the agent's consideration of the smaller class of plans where the value of ?new-ship satisfies the added constraint.

```
(build-plan
  (ReplaceShip Knox ?new-ship))      (1)
  (add-constraint
    ?new-ship
    (< (distance Knox ?new-ship) 500)) (2)
    (build-plan
      (ReplaceShip Knox ?new-ship))    (3)
```

Figure 4: *Add-Constraint*

The metaplan context tree thus inherits its basic structure from the domain plans as reflected in the *build-plan*, *build-subplan*, and *build-subaction* nodes, and as further specified by the instantiation of domain plan variables recorded in *instantiate-var* and *add-constraint* nodes. Because the domain plans occur as arguments to the plan-building metaplans, the metaplan tree turns out to include all the information that would be available from a normal domain plan context tree, so that no separate domain tree structure is needed.

3.3 Query Metaplans

Although the plan-building metaplans that model the exploration of possible plans and the gradual refinement of an intended plan represent the agent's underlying intent, such moves are seldom observed directly in the expert advising setting. The agent's main observable actions are queries of various sorts, requests for information to guide the plan-building choices. While these queries do not directly add structure to the domain plan being considered, they do provide the expert with indirect evidence as to the plan-building choices the agent is considering. A key advantage of the metaplan approach is the precision with which it models the space of possible queries motivated by a given plan-building context, which in turn makes it easier to predict underlying plan-building structure based on the observed queries. The query metaplans include both plan feasibility queries about plan preconditions and slot data queries that ask about the possible fillers for free variables.

3.3.1 Plan Feasibility Queries

The simplest feasibility query metaplan is *ask-pred-value*, which models at any *build-plan* node a query for a relevant value from one of the preconditions of that domain plan. For example, recalling the original *IncreaseGroupReadiness* context in which the *Knox* had been damaged, if the agent's first query in that context is "Where is *Knox*?", the expert's task becomes to extend the context model in a way that explains the occurrence of that query. While that search would need to explore various paths, one match can be found by applying the sequence of metaplans shown in Figure 5.

```

(build-plan
  (IncreaseGroupReadiness
    Knox-group poor good)) (1)
(build-subplan
  (IncreaseGroupReadiness ...)
  (ReplaceShip ...)) (2)
(build-plan
  (ReplaceShip Knox ?new-ship)) (3)
(ask-pred-value
  (ReplaceShip Knox ?new-ship)
  (location-of Knox Knox-loc)) (4)

```

Figure 5: Ask-Pred-Value

The *build-subplan* (2) and *build-plan* (3) nodes, as before, model the agent's choice to consider replacing the damaged ship. Because the *ReplaceShip* domain plan includes among its preconditions (not shown here) a predicate for the location of the damaged ship as the destination for the replacement, the *ask-pred-value* metaplan (4) can then match this query, explaining the agent's question as occasioned by exploration of the *ReplaceShip* plan. Clearly, there may in general be many metaplan derivations that can justify a given query. In this example, the *RepairShip* plan might also refer to the location of the damaged ship as the destination for transporting spare parts, so that this query might also arise from consideration of that plan. Use of such a model thus requires heuristic methods for maintaining and ranking alternative paths, but those are not described here.

The other type of plan feasibility query is *check-pred-value*, where the agent asks a yes/no query about the value of a precondition. As an example of that in a context that also happens to require a deeper search than the previous example, suppose the agent followed the previous query with "Is Roark in the Suez?". Figure 6 shows one branch the search would follow, building down from the *build-plan* for *ReplaceShip* in Figure 5 (3).

```

(build-plan
  (ReplaceShip Knox ?new-ship)) (1)
(instantiate-var
  (ReplaceShip Knox ?new-ship)
  ?new-ship Roark) (2)
(build-plan
  (ReplaceShip Knox Roark)) (3)
(build-subaction
  (ReplaceShip ...) (Sail ...)) (4)
(build-plan
  (Sail Roark Roark-loc Knox-loc)) (5)
(check-pred-value
  (Sail Roark Roark-loc Knox-loc)
  (location-of Roark Roark-loc)) (6)

```

Figure 6: Instantiate-Var and Build-Subaction

Here the search has to go through *instantiate-var* and *build-subaction* steps. The *ReplaceShip* plan has a subaction (*Sail* ?ship ?old-loc ?new-loc) with a precondition (*location-of* ?ship ?old-loc) that can match the condition tested in the query. However, if the existing *build-plan* node (1) were directly expanded by *build-subaction* to a *build-plan* for *Sail*, the ?new-ship variable would not be bound, so that that path would not fully explain the given query. The expert instead must deduce that the agent is considering the Roark as an instantiation for *ReplaceShip*'s ?new-ship, with an *instantiate-var* plan (2) modeling that tentative instantiation and producing a *build-plan* for *ReplaceShip* (3) where the ?new-ship variable is properly instantiated so that its *Sail* sub-action (5) predicts the actual query correctly.

3.3.2 Slot Data Queries

While the feasibility queries ask about the values of plan preconditions, the slot data queries gather data about the possible values of a free plan variable. The most frequent of the slot data query metaplans is *ask-fillers*, which asks for a list of the items that are of the correct type and that satisfy some subset of the precondition requirements that apply to the filler of the free variable. For example, an *ask-fillers* node attached beneath the *build-plan* for *ReplaceShip* in Figure 6 (1) could model queries like "List the frigates." or "List the C1 frigates.", since the ?new-ship variable is required by the preconditions of *ReplaceShip* to be a frigate in the top readiness condition.

An *ask-fillers* query can also be applied to a context already restricted by an *add-constraint* metaplan to match a query that imposes a restriction not found in the plan preconditions. Thus the *ask-fillers* node in line (4) of Figure 7 would match the query "List the C1 frigates that are less than 500 miles from the Knox." since it is applied to a *build-plan* node that already inherits that added distance constraint.

```

(build-plan
  (ReplaceShip Knox ?new-ship)) (1)
(add-constraint
  ?new-ship
  (< (distance Knox ?new-ship) 500)) (2)
(build-plan
  (ReplaceShip Knox ?new-ship)) (3)
(ask-fillers
  ?new-ship
  (ReplaceShip Knox ?new-ship)) (4)

```

Figure 7: Ask-Fillers

Note that it is the query that indicates to the expert that the agent has decided to restrict consideration of possible fillers for the ?new-ship slot to those that are closest and thus can most quickly and cheaply replace the Knox, while the restriction in turn serves to make the query more efficient, since it reduces the number of items that must be included, leaving only those most likely to be useful.

There are three other slot data metaplans that are closely related to *ask-fillers* in that they request information about the set of possible fillers but that do not request that the set be listed in full. The *ask-cardinality* metaplan requests only the size of such a set, as in the query "How many frigates are C1?". Such queries can be easier and quicker to answer than the parallel *ask-fillers* query while still supplying enough information to indicate which planning path is worth pursuing. The *check-cardinality* metaplan covers yes/no queries about the set size, and *ask-existence* covers the bare question whether the given set is empty or not, as in the query "Are there any C1 frigates within 500 miles of Knox?".

In addition to the slot data metaplans that directly represent requests for information, modeling slot data queries requires metaplans that modify the information to be returned from such a query in form or amount. There are three such query modifying metaplans, *limit-cardinality*, *sort-set-by-scalar*, and *ask-attribute-value*. The *limit-cardinality* modifier models a restriction by the agent on the number of values to be returned by an *ask-fillers* query, as in the queries "List 3 of the frigates." or "Name a C1 frigate within 500 miles of Knox.". The *sort-set-by-scalar* metaplan covers cases where the agent requests that the results be sorted based on some scalar function, either one known to be relevant from the plan preconditions or one the agent otherwise believes to be so. The function of *ask-attribute-value* is to request the display of additional information along with the values returned, for example, "List the frigates and how far they are from the Knox.".

These modification metaplans can be combined to model more complex queries. For example, *sort-set-by-scalar* and *ask-attribute-value* are combined in the query "List the C1 frigates in order of decreasing speed showing speed and distance from the Knox.". In the metaplan tree, branches with multiple modifying metaplans show their combined effects in the queries they will match. For example, Figure 8 shows the branch that matches the query "What are the 3 fastest frigates?". The *sort-set-by-scalar* metaplan in line (2) requests the sorting of the possible fillers of the ?new-ship slot on the basis of descending speed, and the

limit-cardinality metaplan in that context then restricts the answer to the first 3 values on that sorted list.

```
(build-plan
  (ReplaceShip Knox ?new-ship))      (1)
(sort-set-by-scalar
  ?new-ship
  (speed-of ?new-ship ?speed)
  descending)                        (2)
(limit-cardinality ?new-ship 3)      (3)
(ask-fillers
  ?new-ship
  (ReplaceShip Knox ?new-ship))      (4)
```

Figure 8: Sort-Set-by-Scalar
and Limit-Cardinality

As shown in these examples, the slot data query metaplans provide a model for some of the rich space of possible queries that the agent can use to get suggestions of possible fillers. Along with the plan feasibility metaplans, they model the structure of possible queries in their relationship to the agent's plan-refining and variable-instantiating moves. This tight modeling of that connection makes it possible to predict what queries might follow from a particular plan-building path and therefore also to track more accurately, given the queries, which plan-building paths the agent is actually considering.

3.4 Comparison with Other Plan-Based Discourse Models

The use of plans to model the domain task level organization of discourse goes back to Grosz's (1977) use of a hierarchy of focus spaces derived from a task model to understand anaphora. Robinson (1980a, 1980b) subsequently used task model trees of goals and actions to interpret vague verb phrases. Some of the basic heuristics for plan recognition and plan tracking were formalized by Allen and Perrault (1980), who used their plan model of the agent's goals to provide information beyond the direct answer to the agent's query. Carberry (1983, 1984, 1985a, 1985b) has extended that into a plan-tracking model for use in interpreting pragmatic ill-formedness and intersentential ellipsis. The approach presented here builds on those uses of plans for task modeling, but adds a layer modeling problem-solving structure. One result is that the connection between queries and plans that is implemented in those ap-

proaches either directly in the system code or in sets of inference rules is implemented here by the query metaplans. Recently, Kautz (1985) has outlined a logical theory for plan tracking that makes use of a classification of plans based on their included actions. His work suggested the structure of plan classes based on effects and preconditions that is used here to represent the agent's partially specified plan during the problem-solving dialogue.

Domain plan models have also been used as elements within more complete discourse models. Carberry's model includes, along with the plan tree, a stack that records the discourse context and that she uses for predicting the discourse goals like *accept-question* or *express-surprise* that are appropriate in a given discourse state. Sidner (1983, 1985) has developed a theory of "plan parsing" for distinguishing which of the plans that the speaker has in mind are plans that the speaker also intends the hearer to recognize in order to produce the intended response. Grosz and Sidner (1985) together have recently outlined a three-part model for discourse context; in their terms, plan models capture part of the intentional structure of the discourse. The metaplan model presented here tries to capture more of that intentional structure than strictly domain plan models, rather than to be a complete model of discourse context.

The addition of metaplans to plan-based models owes much to the work of Wilensky (1983), who proposed a model in which metaplans, with other plans as arguments, were used to capture higher levels of organization in behavior like combining two different plans where some steps overlap. Wilensky's metaplans could be nested arbitrarily deeply, providing both a rich and extensive modeling tool. Litman (1985) applied metaplanning to model discourse structures like interruptions and clarification subdialogues using a stack of metaplan contexts. The approach taken here is similar to Litman's in using a metaplan component to enhance a plan-based discourse model, but the metaplans here are used for a different purpose, to model the particular strategies that shape problem-solving discourse. Instead of a small number of metaplans used to represent changes in focus among domain plans, we have a larger set modeling the problem-solving and query strategies by which the agent builds a domain plan.

Because this model uses its metaplans to capture different aspects of discourse structure than those modeled by Litman's, it also predicts other aspects of agent problem-solving behavior. Because it predicts which queries can be generated by considering particular plans, it can deduce the most closely related

domain plan that could motivate a particular query. For instance, when the agent asked about frigates within 500 miles of Knox, the constraint on distance from Knox suggested that the agent was considering the ReplaceShip plan; a similar constraint on distance from port would suggest a RepairShip plan, looking for a ship to transport replacement parts to the damaged one. Another advantage of modeling this level of structure is that the metaplan nodes capture the stack of contexts on which follow-on queries might be based. In this example, follow-on queries might add a new constraint like "with fuel at 80% of capacity" as a child of the existing *add-constraint* node, add an alternative constraint like "within 1000 miles of Knox" as a sibling, query some other predicate within ReplaceShip, or attach even further up the tree. As pointed out below in Section 6, the metaplan structures presented here can also be extended to model alternate problem-solving strategies like *compare-plan* vs. *build-plan*, thus improving their predictive power through sensitivity to different typical patterns of agent movement within the metaplan tree. The clear representation of the problem-solving structure offered in this model also provides the right hooks for attaching heuristic weights to guide the plan tracking system to the most likely plan context match for each new input. Within problem-solving settings, a model that captures this level of discourse structure therefore strengthens an NL system's abilities to track the agent's plans and predict likely queries.

3.5 Applications and Implementation

This improved ability of the metaplan model to track the agent's problem-solving process and predict likely next moves could be applied in many of the same contexts in which domain plan models have been employed, including anaphora and ellipsis processing and generating cooperative responses. For example, consider the following dialogue where the cruiser Biddle has had an equipment failure:

- Agent: Which other cruisers are
in the Indian Ocean? (1)
Expert: <Lists 6 cruisers> (2)
Agent: Any within 200 miles of Biddle? (3)
Expert: Horne and Belknap. (4)
Agent: Any of them at Diego Garcia? (5)
Expert: Yes, Dale, and there is a supply
flight going out to Biddle tonight. (6)

The agent first asks about other cruisers that may have the relevant spare parts. The expert can deduce from the query in line (3) that the agent is considering SupplySparePartByShip. The "them" in the next query in line (5) could refer either to all six cruisers or to just the two listed in (4). Because the model does not predict the Diego Garcia query as relevant to the current plan context, it is recognized after search in the metaplan tree as due instead to a SupplyPart-ByPlane plan, with the change in plan context implying the correct resolution of the anaphora and also suggesting the addition of the helpful information in (6). The metaplan model of the pragmatic context thus enables the NL processing to be more robust and cooperative.

The Pragma system in which this metaplan model is being developed and tested makes use of the pragmatic model's predictions for suggesting corrections to ill-formed input. Given a suitable library of domain plans and an initial context, Pragma can expand its metaplan tree under heuristic control identifying nodes that match each new query in a coherent problem-solving dialogue and thereby building up a model of the agent's problem-solving behavior. A domain plan library for a subset of naval fleet operations plans and sets of examples in that domain have been built and tested. The resulting model has been used experimentally for dealing with input that is ill-formed due to a single localized error. Such queries can be represented as underspecified logical forms containing "wildcard" terms whose meaning is unknown due to the ill-formedness. By searching the metaplan tree for queries coherently related to the previous context, suggested fillers can be found for the unknown wildcards. For the roughly 20 examples worked with so far, Pragma returns between 1 and 3 suggested corrections for the ill-formed element in each sentence, found by searching for matching queries in its metaplan context model.

3.6 Extensions to the Model and Areas for Further Work

This effort to capture further levels of structure in order to better model and predict the agent's behavior needs to be extended both to achieve further coverage of the expert advising domain and to develop models on the same level for other discourse settings. The current model also includes simplifying assumptions about agent knowledge and cooperativity that should be relaxed.

Within the expert advising domain, further classes of metaplans are required to cover informing and evaluative behavior. While the expert can usually deduce the agent's plan-building progress from the queries, there are cases where that is not true. For example, an agent who was told that the nearest C1 frigate was the Wilson might respond "I don't want to use it.", a problem-solving move whose goal is to help the expert track the agent's planning correctly, predicting queries about other ships rather than further exploration of that branch. Informing metaplans would model such actions whose purpose is to inform the expert about the agent's goals or constraints in order to facilitate the expert's plan tracking. Evaluative metaplans would capture queries whose purpose was not just establishing plan feasibility but comparing the cost of different feasible plans. Such queries can involve factors like fuel consumption rates that are not strictly plan preconditions. The typical patterns of movement in the metaplan tree are also different for evaluation, where the agent may compare two differently-instantiated *build-plan* nodes point for point, moving back and forth repeatedly, rather than following the typical feasibility pattern of depth-first exploration. Such a comparison pattern is highly structured, even though it would appear to the current model as patternless alternation between *ask-pred-value* queries on two different plan branches. Metaplans that capture that layer of problem-solving strategy would thus significantly extend the power of the model.

Another important extension would be to work out the metaplan structure of other discourse settings. For an example closely related to expert advising, consider two people trying to work out a plan for a common goal; each one makes points in their discussion based on features of the possible plan classes, and the relationship between their statements and the plans and the strategy of their movements in the plan tree could be formalized in a similar system of metaplans.

The current model also depends on a number of simplifying assumptions about the cooperativeness and knowledge of the agent and expert that should be relaxed to increase its generality. For example, the model assumes that both the expert and the agent have complete and accurate knowledge of the plans and their preconditions. As Pollack (1986) has shown, the agent's plan knowledge should instead be formulated in terms of the individual beliefs that define what it means to have a plan, so the model can handle cases where the agent's plans are incomplete or incorrect. Such a model of the agent's beliefs could also be a major factor in the heuristics of plan tracking, identifying, for example, predicates whose

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value the agent does not already know which therefore are more likely to be queried. The current model should also be extended to handle multiple goals on the agent's part, examples where the expert does not know in advance the agent's top-level goal, and cases of interactions between plans.

However, no matter how powerful the pragmatic modeling approach becomes, there is a practical limitation in the problem-solving setting on the amount of data available to the expert in the agent's queries. More powerful, higher level models require that the expert have appropriately more data about the agent's goals and problem-solving state. That tradeoff explains why an advisor who is also a friend can often be much more helpful than an anonymous expert whose domain knowledge may be similar but whose knowledge of the agent's goals and state is weaker. The goal for cooperative interfaces must be a flexible level of pragmatic modeling that can take full advantage of all the available knowledge about the agent and the recognizable elements of discourse structure while still avoiding having to create high-level structure for which the data is not available.

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4. Rapid Porting of the ParlanceTM Natural Language Interface

Madeleine Bates⁵

Abstract

Developing knowledge bases for AI systems takes too long and costs too much. Even a "portable" system is expensive to use if its installation takes a long time or requires the labor of scarce, highly-trained people. BBN has recently created a tool for acquisition which dramatically reduces the time and cost of installing a natural language system.

During 1988, BBN used its LearnerTM tool to configure the ParlanceTM database interface to two different versions of a large Navy database. The configuration process was performed primarily with development versions of the Learner, which is a software tool for creating the knowledge bases, vocabulary, and mappings to the database that enable the Parlance interface to understand questions addressed to a particular database. The Learner reduced the time required to create Parlance configurations from months to weeks, and demonstrated that the Learner works effectively on databases with many hundreds of fields.

4.1 Introduction

4.1.1 The Navy's IDB Database

The IDB (hereafter called the Navy database) is a large, evolving database being used in the Fleet Command Center at the Navy's Pacific Fleet headquarters in Pearl Harbor, Hawaii [1]. It has dozens of tables and hundreds of fields containing information about hundreds of U.S. ships, planes and other units, as well as more limited data on foreign units.

Examples of the kind of information that may be available for a particular unit are: its home port, current location, current employments (an employment

is a complex concept including destination, projected arrival time, purpose, etc.), type and amount of equipment on board, various types of readiness status (personnel readiness, equipment readiness, overall readiness, etc.), and operating characteristics (average cruising speed, maximum speed, fuel capacity, etc.). Other data in this database include detailed information about the characteristics of various types of equipment (e.g., the firing rate of guns) and properties of geographic entities (e.g., for ports, the country they are in, and whether they have a deep channel).

The Navy database provides basic data for systems under development at the Fleet Command Center. This database offers a rich environment for a natural language interface, because the need to explore the database with ad hoc queries occurs frequently.

4.1.2 The Parlance Interface

The Parlance interface from BBN Systems and Technologies Corporation is an English language database front end. It has a number of component parts: a graphical user interface, a language understander that translates English queries into database commands for relational database systems such as Oracle and VAX Rdb, a control structure for interacting with the user to clarify ambiguous queries or unknown words, and a dbms driver to call the database system to execute database commands and to return retrieved data to the user.

The Parlance system uses several domain-dependent knowledge bases:

1. A domain model, which is a class-and-attribute representation of the concepts and relationships that the Parlance user might employ in queries.
2. A mapping from this domain model to

⁵This paper is a reprint of a paper that appears in *Proceedings of the Speech and Natural Language Workshop*, Morgan Kaufmann Publishers, Inc., San Mateo, CA, February, 1989.

the database, which specifies how to find particular classes and attributes in terms of the database tables and fields of the underlying dbms.

3. A vocabulary, containing the lexical syntax and semantics of words and phrases that someone might use to talk about the classes and attributes.
4. Miscellaneous additional information about how information is to be printed out (for example, column headers that are different from field names in the database).

The Learner is used to create these knowledge bases.

The following queries illustrate the kinds of questions that one can ask the Parlace system after it is configured for the Navy database:

What's the maximum beam of the Kitty Hawk?

Show me the ships with a personnel resource readiness of C3.1

List the ships that are C1 or C2.

Is the Frederick conducting ISE in San Diego?

How many ships aren't NTDS capable?

Which classes have a larger fuel capacity than the Wichita?

How many submarines are in each geo region.

Are there any harpoon capable C1 ships deployed in the Indian Ocean whose ASW rating is M1?

List them.

Show the current employment of the carriers that are C3 or worse, sorted by overall readiness.

Where is the Carl Vinson?⁶

What are the positions of the friendly subs?

⁶This query is ambiguous. It may be asking for a geographical region or for a latitude and longitude. The Parlace system recognizes the ambiguity and asks the user for clarification.

4.1.3 The Learner

The Learner is a software tool that creates the domain-dependent knowledge bases that the Parlace system needs. It "learns" what Parlace needs to know from several sources:

1. The database system itself (i.e., the dbms catalogue that describes the database structure, and the values in various fields of the database).
2. A human teacher (who is probably a database administrator, someone familiar with the structure of the database, but who is not a computational linguist or AI expert).
3. A core domain model and vocabulary that are part of the basic Parlace system.
4. Inferences (about such things as morphological and syntactic features) that the Learner makes (subject to correction and modification by the teacher).

Figure 1 shows the input and output structure of the Learner. We call the process of using the Learner configuring Parlace for a particular application.

The human teacher uses the Learner by stepping through a series of menus and structured forms. The Learner incrementally builds a structure that can be output as the knowledge bases shown in Figure 1.

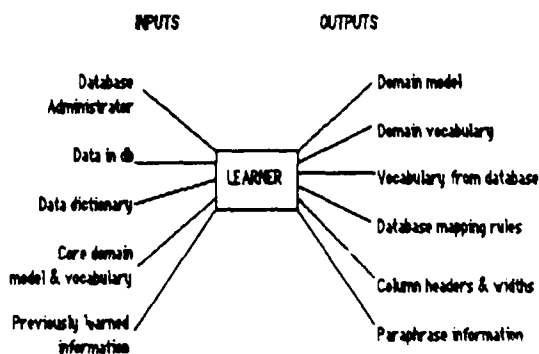


Figure 1. The Structure of the Learner

The teacher chooses particular actions and is led through steps which elicit related information that

Parlance must know. For example, when the teacher designates that a particular table or set of tables belong to a class named "ship", the Learner immediately allows the teacher to give synonyms for this class, such as "vessel". The Learner will then infer that the plural form of the synonym is "vessels", instead of making the teacher supply the plural form, although the teacher can easily correct the Learner if the word has an irregular plural.

Whenever information is optional, the teacher can decline to specify it at the first opportunity, and can later initiate an action to provide it. Both required and optional information can be changed by the teacher using the Learner's editing capabilities.

The ability to assign names freely, the freedom to do many operations in the sequence that makes the most sense to the person using the Learner, and the fact that the Learner expresses instructions and choices in database terms wherever possible, make it easy for database administrators who are not computational linguists or AI experts to configure the Parlance interface.

4.2 Configuring Parlance

Before the Learner existed, Parlance configurations were created "by hand". That is, highly skilled personnel had to use a separate set of programs (including a Lisp editor) to create the appropriate configuration files.

Figure 2 compares this by-hand configuration process with the first experience using the Learner on the Navy database. The two examples used different databases, but in each case we began with a large set of sample queries in the target domain, and periodically tested the developing configuration by running those queries through the Parlance system. We measured our progress by keeping track of the number of those queries the system could understand as the configuration process went on. Figure 2 actually considerably understates the productivity enhancement realized with the Learner, because the personnel database used for the by-hand configuration was much smaller and less complex than the Navy database.

The Navy database used to test the first version of the Learner was considerably restructured and enlarged, and we had an opportunity to configure Parlance for the newer database. Since we had a new,

improved version of the Learner, we chose to configure Parlance to the second version of the Navy database "from scratch", rather than by building on the results of the first configuration. This gave us an opportunity to measure the effort required to use the Learner to do a much larger system configuration, since the size of the target database (measured in terms of the number of fields) had nearly tripled.

The results in Figure 3 and its accompanying notes show that the Learner robustly scaled up to the task, and that the time required to perform the configuration increased much less than the number of fields in the database, the vocabulary size, or any other simple metric of size. In fact, for a modest 1/3 increase in configuring effort, a configuration roughly 3 times larger was created.

Notes to accompany Figure 3:

- (0) Changes in the underlying system since this configuration was created make it impossible to measure some of the numbers in this column accurately, so the numbers dealing with vocabulary are estimates.
- (1) Records were not kept at the time this configuration was created, but the configuration happened over a period of months.
- (2) That this level of effort includes not just time spent using the Learner but also time required to understand the domain, and to do some testing and revision. About 60% of this time was spent using the development version of the Learner.
- (3) Records were not kept at the time this configuration was done, but it involved many person-months.
- (4) This estimate includes inflected forms of regular words and some words that were acquired directly from database fields.
- (5) This includes words read from the database and all words directly represented in the vocabulary; it excludes inflected forms of morphologically regular words.
- (6) This is a rough measure of the semantic complexity of the domain, since it excludes words that are abbreviations or synonyms.

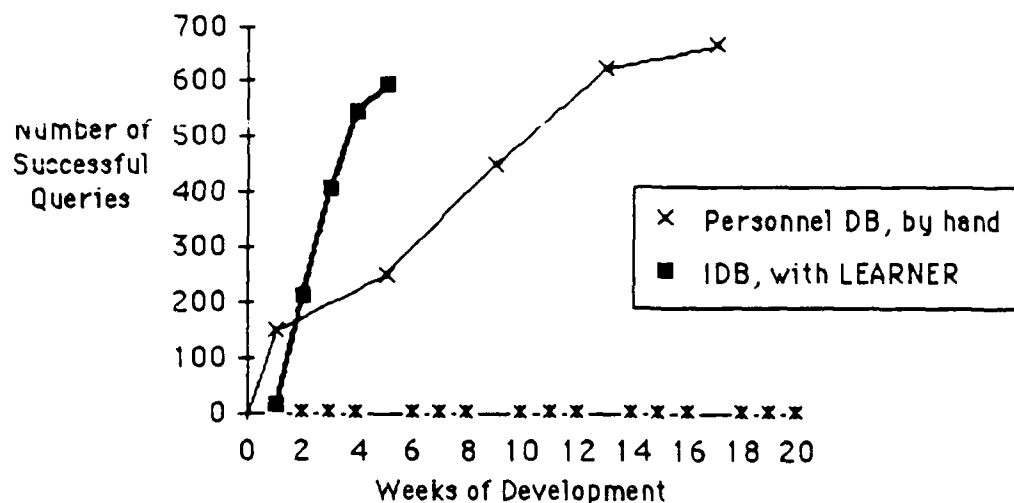


Figure 2. Speed-up of acquisition using the Learner

	<u>Personnel</u> <u>Configuration (0)</u>	<u>1st Navy</u> <u>Configuration</u>	<u>2nd Navy</u> <u>Configuration</u>
Elapsed time	(1)	4 weeks	6 weeks
Total level of effort (2)	(3)	6+ per.wks.	8+ per. wks.
Tables in database	31	32	75
Fields in database	133	231	666
Classes in domain model	218	83	303
Attributes in domain model	316	160	680
Estimated total vocabulary (4)	3000	5500	9800
Root forms (5)	1700	3282	6354
Proper nouns read from db	1170	2656	3907
Verbs	65	6	36
Words with semantics (6)	1600	3326	6073

Figure 3. Comparing the Configuration Processes and Results

4.3 Conclusions

The Learner⁷ significantly reduces the time required to create configurations of the Parlane natural language interface for databases with hundreds of fields from months to weeks. This dramatic speed-up in knowledge acquisition scales up robustly, and works as effectively on large databases as it does on small ones.

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5. Strategies for Effective Paraphrasing

Marie Meteor, Varda Shaked⁸

Abstract

In this paper we present a new dimension to paraphrasing text in which characteristics of the original text motivate strategies for effective paraphrasing. Our system combines two existing robust components: the IRUS-II NL understanding system and the Spokesman generation system. We describe the architecture of the system and enhancements made to these components to facilitate paraphrasing. We particularly look at how levels of representation in these two systems are used by specialists in the paraphraser which define potential problems and paraphrasing strategies. Finally, we look at the role of paraphrasing in a cooperative dialog system. We will focus here on paraphrasing in the context of natural language interfaces and particularly on how multiple interpretations introduced by various kinds of ambiguity can be contrasted in paraphrases using both sentence structure and highlighting and formatting the text itself.

5.1 Introduction⁹

While technically paraphrasing is simply the task of restating the meaning of a text in a different form.

⁸We would like to thank Lance Ramshaw for his invaluable help in understanding the inner workings of RUS and suggestions of where it could be augmented for our purposes, and Dawn MacLaughlin for her implementation of Parrot, the initial version of our paraphraser. We would also like to thank Ralph Weischedel, Damaris Ayuso, and David McDonald for their helpful comments of drafts of this paper and Lyn Bates for early inspirations.

it is crucial to consider the purpose of the paraphrase in order to motivate particular strategies for changing the text. If the point of the paraphrase is to clarify the original text, as in a natural language (NL) interface to a database or expert system application, then disambiguating the query and choosing more precise lexical items (perhaps closer to the structure of the actual DB, expert system, or other underlying application) are essential strategies. If the point is to summarize information, then strategies for evaluating the relative importance of the information presented in the text is necessary. If the point is merely to restate the text differently than the original, perhaps merely to exercise the system, then one must use strategies which consider what structures and lexical items were actually found by the parser.

Our motivation for work on strategies for effective paraphrasing comes from the recent availability of NL interfaces as commercial products. As the underlying systems that a NL interface must interact with increase in number and sophistication, the range of NL interactions will increase as well. Paraphraser developed in the past (e.g. McKeown's Co-op and Bates & Bobrow's ParlanceTM software) were all limited in that each used only a single strategy for paraphrasing regardless of what problems may have been present in the original query. (We discuss these systems in detail in Section 6.) Our approach is to develop a variety of strategies which may be employed in different situations. We introduce a new dimension to paraphrasing text in which characteristics of the original text plus the overall context (including the goal of the system) motivate strategies for effective paraphrasing.

Our focus here will be on paraphrasing ambiguous queries in an interactive dialog system, where contrasting multiple interpretations is essential. In order to ground our discussion, we first look briefly at a range of ambiguity types. We then

⁹This paper is reprinted from the *Proceedings of the 27th Annual Meeting of the 12th International Conference on Computational Linguistics*, 22-27 August 1988, Budapest Hungary. Requests for copies should be addressed to:

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provide an overview of the architecture and description of the two major components: the IRUS-II™ understanding system and the Spokesman generation system. We look closely at the aspects of these systems that we augmented for the paraphrasing task and provide a detailed example of how the system appreciates multiple interpretations and uses that information to govern decision making in generation. Next we discuss the role of paraphrasing in a cooperative dialog system, and in the final section we contrast our approach with other work in paraphrasing.

5.2 Problems and Strategies

Ambiguity is one of the more difficult problems to detect and correct. In this section we look at three kinds of ambiguity: lexical, structural and contextual, and discuss potential strategies a paraphraser might use to eliminate the ambiguity.

1) LEXICAL AMBIGUITIES are introduced when a lexical item can refer to more than one thing. In the following example "Manhattan" can refer to either the borough of New York City or the ship:

What is the latitude and longitude of Manhattan?

The paraphraser must appreciate the ambiguity of that noun phrase, decide how to disambiguate it, and decide how much of the context to include in the paraphrase. One strategy would be to repeat the entire query, disambiguating the noun phrase by using the type and name of the object:

Do you mean what is the latitude and longitude of the city Manhattan or what

is the latitude and longitude of the ship Manhattan?

However, if the query is long, the result could be quite cumbersome. A different strategy, highlighting and formatting the text, can serve to direct the user's attention to the part that is ambiguous:

Do you mean list the latitude and longitude of the city Manhattan or the ship Manhattan?

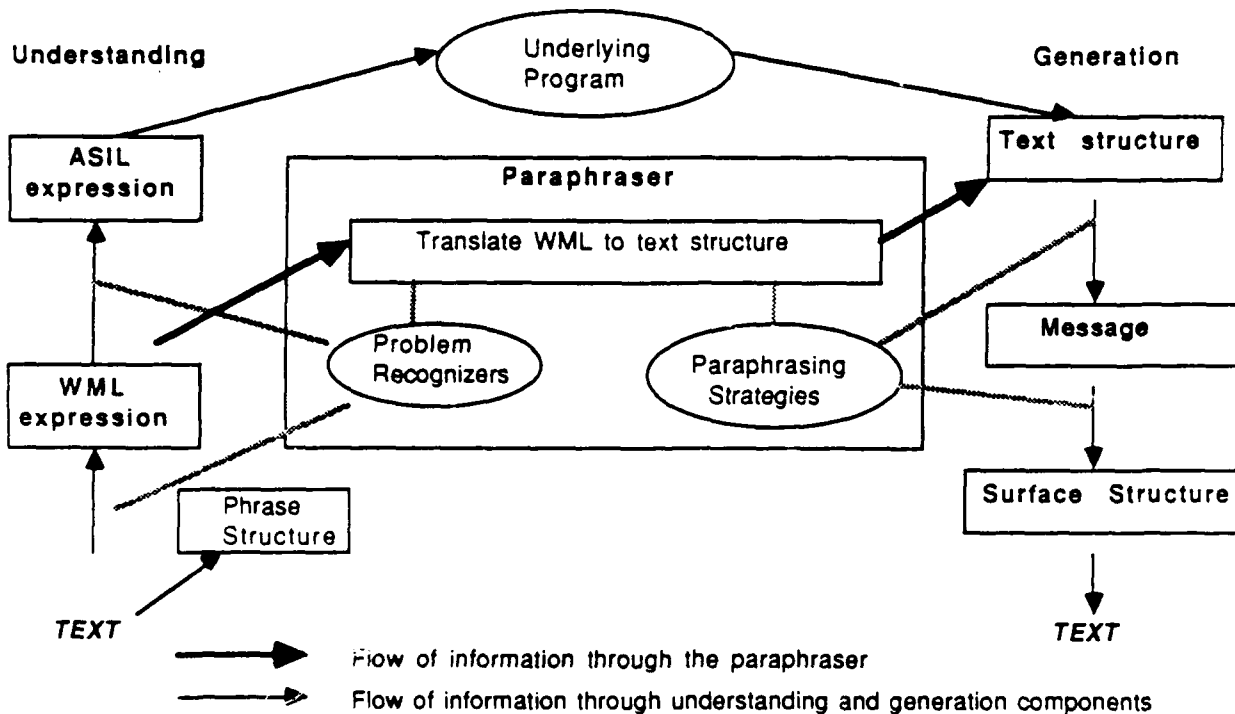


Figure 9: Architecture of the Paraphraser

2) STRUCTURAL AMBIGUITIES are caused when there are multiple parses for a sentence. Conjunction is a typical source of structural ambiguity. Modifiers of conjoined NPs may distribute over each NP or modify only the closest NP. Consider, for example, the following query:

Display the forested hills and rivers.

This query has only one interpretation in which the premodifier "forested" modifies only the noun "hills". In contrast the following query has two interpretations:

Display the C1 carriers and frigates

In one interpretation, the premodifier "C1" may apply only to the noun "carrier" in the other, "C1" applies to both "carriers" and "frigates". Each interpretation requires a different paraphrase strategy. In the case where the premodifier distributes, the ambiguity may be eliminated by repeating the modifier: *Display the C1 carriers and C1 frigates*. When it does not distribute, there are three potential strategies:

--changing the order of the conjuncts: *Display the frigates and C1 carriers*.

--introducing explicit quantifiers: *Display the C1 carriers and all the frigates*.

--moving premodifiers to postmodifiers: *Display the carriers which are C1 and the frigates*.

3) CONTEXTUAL AMBIGUITIES are introduced when the query is underspecified for the underlying system it is working with. For example if the context includes a map and the possibility of natural language or table output, the query *Which carriers are C1?* could mean either *list* or *display*.

5.3 Architecture

As the examples above illustrate, the information needed to notice problems such as ambiguity in a query is quite varied, and the strategies needed to generate a motivated paraphrase must be employed at various levels in the generation process. A distinguishing feature of our system is that it works in cooperation with existing understanding and generation components and allows the paraphraser access to multiple levels of their processing. This multilevel design allows the understanding system to appreciate ambiguities and vagueness at lexical, structural, and contextual levels, and the generation system to affect

the text's organization, syntactic structure, lexical items and even to format and highlight the final text.

Figure 9 shows an overview of the architecture of the system. In this section, we first describe the understanding and generation systems independently, particularly at how the problem recognizers and paraphrasing strategies have been incorporated into the components. We then look at the paraphraser itself and how it evolved.

5.3.1 The Understanding Component: IRUS-II(TM) NL Software

IRUS-IITM (Weischedel, et al. 1987) is a robust natural language understanding system that interfaces to a variety of underlying systems, such as DB management systems, expert systems and other application programs. It is capable of handling a very wide range of English constructions including ill-formed ones.

5.3.1.1 IRUS-II - Components and design principals

IRUS-II has two major processing levels which distinguish the linguistic processing from the details of the particular underlying systems it is used with. The first level, the "Front End", integrates syntactic and semantic processing. The major domain-independent "Front End" modules include a parser and associated grammar of English, a semantic interpreter, and a subsystem for resolving anaphora and ellipsis. These modules simultaneously parse an English text into a syntactic structural description and construct a formal semantic representation of its meaning in a higher order intensional logic language called the World Model Language (WML). The syntactic processor is the RUS Grammar/Parser which is based on the ATN formalism. Constants in the WML are concepts and predicates from a hierarchical domain model represented in NIKL. (Moser 1983).

The more domain dependent modules of the Front End are the lexicon, domain model, and a set of semantic Interpretation Rules (IRules). The lexicon contains the information about parts of speech, and syntactic and morphological features needed for parsing, and word and phrase substitutes (such as abbreviations). An IRule defines, for a word or (semantic) class of words, the semantically acceptable English phrases that can occur having that word as a head of the phrase, and in addition defines the

semantic interpretation of an accepted phrase. Thus, when the parser proposes (i.e., TRANSMITs) an intermediate syntactic phrase structure, the semantic interpreter uses the IRules that are associated with the head of that phrase to determine whether the proposed structure is interpretable and to specify its interpretation. Since semantic processing is integrated with syntactic processing, the IRules serve to block a semantically anomalous phrase as soon as it is proposed by the parser. The semantic representation of a phrase is constructed only when the phrase is believed complete.

The task of the "Back End" component of IRUS is to take a WML expression and compute the correct command or set of commands to one or more underlying systems, obtaining the result requested by the user. This problem is decomposed into the following steps:

- The WML expressions is simplified and then gradually translated into the Application System Interface Language (ASIL).
- The particular underlying system or systems that need to be accessed are identified.
- The ASIL is transformed into underlying system(s) code to execute the query.

While the constants in WML and ASIL are domain-dependent, the constants in ASIL-to-code translation system(s) code are both domain dependent and underlying-system dependent.

5.3.1.2 Ambiguity Handling by the IRUS-II system - Overview

In this section, we briefly describe how various kinds of ambiguities are currently handled in IRUS-II. There are at least the following kinds of ambiguities that may occur in natural language: Semantic ambiguity (lexical, phrasal, referring expressions), structural ambiguity, quantifier scope ambiguity and collective reading ambiguity. In cases of semantic ambiguity, multiple WMLs are generated from the same syntactic parse path. For example, when a word (e.g., "Manhattan") belongs to more than one semantic class in the domain model (e.g., CITY, VESSEL), two WMLs are generated from the same syntactic parse path, each referring to the different semantic class. Similarly, nouns premodified by nouns/adjectives (e.g., "Hawaii ships") generate multiple WMLs, each created as a result of multiple

IRules assigning several interpretations to the modified noun (e.g., "Ships whose home port is Hawaii", "Ships whose destination is Hawaii", or "Ships whose current location is Hawaii").

Structural ambiguities are caused by multiple syntactic interpretations and result in alternative parse paths in the RUS parser/grammar. IRUS-II identifies these ambiguities by sequentially attempting to parse the text, with each attempt following a different parse path. Note in these cases each syntactic parse path may also have multiple semantic interpretations.

5.3.1.3 Enhancements to IRUS-II for effective paraphrasing

Though IRUS-II produces multiple interpretations (WMLs) for a variety of ambiguous sentences, it was not originally designed with the intent of paraphrasing those interpretations. While each individual WML could be paraphrased separately, a more useful approach would be to combine closely related interpretations into a single paraphrase that highlights the contrasts between the interpretations. The need to keep associations between multiple interpretations motivated the following enhancements to the IRUS-II system:

- Predefined ambiguity specialists that detect and annotate potential problems presented by the input text are "distributed" in the parser/grammar and the semantic interpreter. For example, when the parser TRANSMITs the phrase "Manhattan" to the semantic interpreter as a head of a noun phrase (NP), two semantic classes, CITY and VESSEL, will be associated with that NP. At this point, the Lexical Ambiguity Specialist will record the lexical item "Manhattan" as the ambiguity source and the two different classes.
- After recording the potential ambiguity source, each ambiguity specialist monitors a predefined sequence of TRANSMITs associated with that source, and records the different intermediate WML expressions resulting from these TRANSMITs. For example, the Lexical Ambiguity Specialist monitors the TRANSMITs of "Manhattan" as a head noun of the NP. In this case, there will be two applicable

IRules, one defining "Manhattan" as a CITY and the other defining "Manhattan" as a VESSEL. Both interpretations are semantically acceptable, resulting in two intermediate WMLs, which are then recorded by the specialist. Upon completion of the input text, two WMLs will be created and this record will be used to annotate them with their respective differences that resulted from a common ambiguity source.

We look at the details of the specialists on one particular example in Section 4.

5.3.2 The Generation System: SPOKESMAN

The Spokesman generation system also has two major components: a text planner and a linguistic realization component, Mumble-86 (Meteer et al. 1987). Both components are built within the framework of "multilevel, description directed control" (McDonald 1983, McDonald & Pustejovsky 1987). In this framework, decisions are organized into levels according to the kind of reference knowledge brought to bear (e.g. event or argument structure, syntactic structure, morphology). At each level, a representation of the utterance is constructed which both captures the decisions made so far and constrains the future decision making. The representation at each level also serves as the control for the mapping to the next level of representation.

The text planner must establish what information the utterance is to include and what wording and organization it must have in order to insure that the information is understood with the intended perspectives. The intermediate level of representation in this component is the text structure, which is a tree-like representation of the organization of discourse level constituents. The structure is populated with model level objects (e.g. from the applications program) and "discourse objects" (compositional objects created for the particular utterance) and the relations between these objects. The text structure is extended incrementally in two ways:

- 1) expanding nodes whose contents are composite objects by using predefined templates associated with the object types (such as expanding an "event" object by making its arguments subnodes);

- 2) adding units into the structure at new nodes.

The units may be selected from an already positioned composite unit or they may be individuals handed to the orchestrator by an independently driven selection process.

Once the text structure is complete, it is traversed depth first beginning with the root node. At each node, the mapping process chooses the linguistic resource (lexical item, syntactic relation such as restrictive modifier, etc.) that is to realize the object which is the contents of that node. Templates associated with these objects define the set of possibilities and provide procedures for building its portion of the next level of representation, the "message level", which is the input specification for the linguistic realization component, MUMBLE-86.

The input specification to MUMBLE-86 specifies what is to be said and constrains how it is to be said. MUMBLE-86 handles the realization of the elements in the input specification (e.g. choosing between *the ships are assigned*, *which are assigned*, or *assigned* depending on whether the linguistic context requires a full clause, postmodifier, or premodifier), the positioning of elements in the text (e.g. choosing where to place an adverbial phrase), and the necessary morphological operations (e.g. subject-verb agreement).

In order to make these decisions, MUMBLE-86 maintains an explicit representation of the linguistic context in the form of an annotated surface structure. Labels on positions provide both syntactic constraints for choosing the appropriate phrase and a definition of which links may be broken to add more structure. This structure is traversed depth first as it is built, guiding the further realization of embedded elements and the attachment of new elements. When a word is reached by the traversal process, it is sent to the morphology process, which uses the linguistic context to execute the appropriate morphological operations. Then the word is passed to the word stream to be output and the traversal process continues through the surface structure.

5.3.2.1 Parrot and Polly

Our first implementation of the paraphraser was simply a parrot which used the output of the parser (the WML) as input to the generator. The text planner in this case consists of a set of translation functions which build text structure and populate it with composite objects built from WML subexpressions and the constants in the WML (concepts and roles from IRUS's hierarchical domain model). The translation to text structure uses both explicit and implicit information from the WML. The first operator in a

WML represents the speech act of the utterance. For example, bring-about indicates explicitly that the matrix clause should be a command and implicitly that it should be in the present tense and the agent is the system. The iota operator indicates that the reference is definite and power indicates it is plural.

A second set of templates map these objects to the input specification for the linguistic component, determining the choice of lexical heads, argument structures, and attachment relations (such as restrictive-modifier or clausal-adjunct).

Interestingly, parrot turned out to be a conceptual parrot, rather than a verbatim one. For example, the phrase *the bridge on the river* is interpreted as the following wml expression. The domain model predicate CROSS representing the role between *bridge* and *river* because IRUS interprets "on" in this particular context in terms of the CROSS relation:

```
(IOTA JX124 BRIDGE (CROSS JX124
(IOTA JX236 RIVER)))
```

This is "parroted" as *the bridge which crosses the river*. While in some cases this direct translation of the wml produces an acceptable phrase, in other cases the results are less desirable. For example, named objects are represented by an expression of the form (IOTA var type (NAME var name)), which, translated directly, would produce *the river which is named Hudson*. Such phrases make the generated text unnecessarily cumbersome. Our solution in PARROT was to implement an optimization at the point when the complex object is built and placed in the text structure that uses the name as the head of the complex object rather than the type. (Melish, 1987, discusses similar optimizations in generating from plans.)

While PARROT allowed us to establish a link from text in to text out, it is clear this approach is insufficient to do more sophisticated paraphrasing. POLLY, as we call our "smart" paraphraser, takes advantage of the extra information provided by IRUS-II in order to control the decision making in generation.

One of the most common places in which the system must choose carefully which realization to use is when the input is ambiguous and the paraphrase must contrast the two meanings. For example, if a semantic ambiguity is caused by an ambiguous name, as in *Where is Diego Garcia* (where Diego Garcia is both a submarine and a port), the type information must be included in the paraphrase:

*Do you mean where is the port Diego Garcia
or the submarine Diego Garcia.*

Note, with the optimization of PARROT described above, this sentence could not be disambiguated.

In order to generate this paraphrase contrasting the two interpretations, the system needs to know what part is ambiguous at two different points in the generation process: in the text planner when selecting the information to include (both the type and the name) and at the final stage when the text is being output (to change the font). Our use of explicit active representations allows the system to mark the contrast only once, at the highest level, the text structure. This constraint is then passed through the levels and can effect decisions at any of the lower levels. Thus the system makes use of the information provided by the understanding system when it is available and ensures it will still be available when needed and won't be considered in parts of the utterance where it is not relevant.

5.4 Paraphrasing Syntactic Ambiguities - an Example

To elucidate the description above, we will return to an earlier example of a query with an ambiguous conjunction construction: *Display all carriers and frigates in the Indian Ocean*. This sentence has two possible interpretations:

- 1) *Display all carriers in the Indian Ocean and all frigates in the Indian Ocean.*
- 2) *Display all frigates in the Indian Ocean and all the carriers.*

In this example we show (1) how the Problem Recognizers discover that there are two interpretations and what the particular differences are; and (2) how the Paraphrasing Strategies use that information in the translation to text structure and the generation of the paraphrase.

5.4.1 Phase 1: The Problem Recognizers

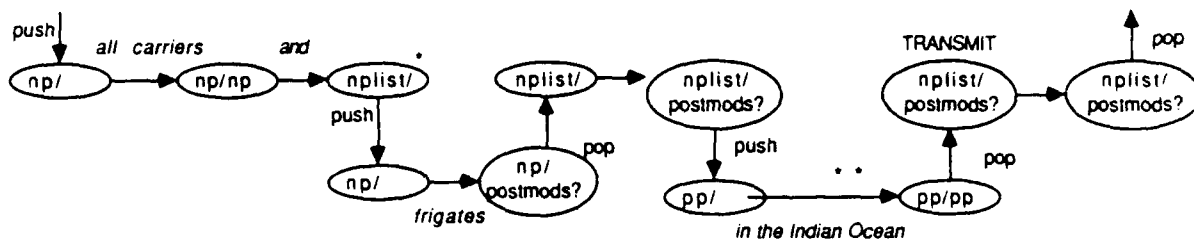
As we discussed earlier, problem recognizing specialists have been embedded in the understanding system. Here we look at the Noun-Phrase (NP) Conjunction Ambiguity specialist and the two parse paths that correspond to the parses resulting from a NP conjunction ambiguity (see Figure 10).

The first task of this specialist is to annotate the parse path when a NP conjunction is encountered by the parser. In IRUS-II, when the RUS parser has completed the processing of the first NP *the frigates* and the conjunction word *and*, it attempts (among other alternatives) to parse the next phrase as a NP. At this point the Conjunction Ambiguity Specialist annotates that parse path with a NP-CONJUNCTION-AMBIGUITY tag (depicted in Figure 10 with * at the first NPLIST/ state in both parse paths 1 and 2). This annotation will allow the different interpretations that may result

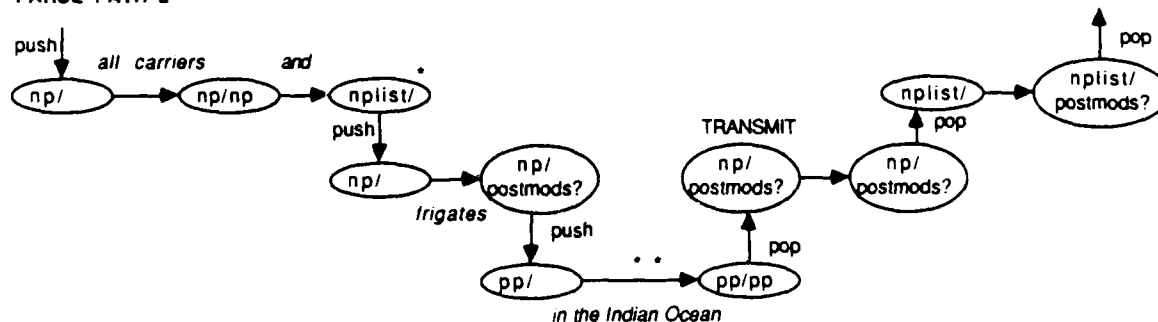
from this NP conjunction to be grouped later according to their common ambiguity source. (Note that if not using an ATN, appropriate annotations can be made using structure building rules associated with the grammar rules). The paraphraser can then organize its paraphrases according to a group of related ambiguous interpretations. As previously stated, it is believed that simultaneously observing closely related interpretations is more effective than presenting randomly generated paraphrases that correspond to arbitrary parse paths.

The second task of the NP Conjunction Ambiguity specialist is to monitor those TRANSMITs to the Semantic Interpreter that may result in multiple interpretations (WMLs) from the same source of ambiguity. Thus, starting from when the possible ambiguity has been noticed, this specialist will monitor the TRANSMITs to all the modifiers of the NPs. In our example, the NP Conjunction Ambiguity specialist monitors the TRANSMITs of the prepositional phrase (PP) *in the Indian Ocean* to all

PARSE PATH 1



PARSE PATH 2



* Set conjunction ambiguity tag

** Conjunction ambiguity specialist monitors tagged transmits to semantic interpreter

Figure 10: Parse Paths

NPs annotated with the NP-CONJUNCTION-AMBIGUITY tag (TRANSMITs are illustrated with **), which include the TRANSMITs of that PP as a postmodifier to each of the conjoined NPs (parse path 1) as well as to only the second NP (parse path 2). Since the PP *in the Indian Ocean* is semantically acceptable as a postmodifier in both parse paths, two intermediate WMLs will be created:

Intermediate WML-1:

```
(SETOF (IOTA ?JX19 (POWER CARRIER)
          (UNITS.LOCATION ?JX19 IO))
  (IOTA ?JX20 (POWER FRIGATE)
          (UNITS.LOCATION ?JX20 IO)))
```

Intermediate WML-2:

```
(SETOF (IOTA ?JX19 (POWER CARRIER)
          (IOTA ?JX20 (POWER FRIGATE)
          (UNITS.LOCATION ?JX20 IO)))
```

Each intermediate WML contains a SETOF operator with two arguments that represent a pair of conjoined NPs. In Intermediate WML-1 both arguments have the UNITS.LOCATION restriction, and in Intermediate WML-2 only the second argument has that restriction. The NP Conjunction Ambiguity specialist annotates those intermediate WMLs, and the parser proceeds to complete the processing of the input text. In our example, two final WMLs are generated, one for each of two SETOF expressions that originated from the same NP-CONJUNCTION-AMBIGUITY source:

```
WML-1: (BRING-ABOUT
  ((INTENSION
    (EXISTS ?JX18 LIST
      (OBJECT.OF ?JX18
        <Interm-WML-1>)))
    TIME WORLD))
```

```
WML-2: (BRING-ABOUT
  ((INTENSION
    (EXISTS ?JX18 LIST
      (OBJECT.OF ?JX18
        <Interm-WML-2>)))
    TIME WORLD))
```

ANNOTATION:

```
(NP-CONJUNCTION-AMBIGUITY
  (Parse-Path-1
    Interps (WML-1<Interm-WML-1>))
  (Parse-Path-2
    Interps (WML-2<Interm-WML-2>)))
```

More complex sentences that contain postmodified NP conjunction may have additional in-

terpretations. For instance, the sentence *The carriers were destroyed by frigates and subs in the Indian Ocean* may have a third interpretation in which the PP *in the Indian Ocean* modifies the whole clause. Another more complex example is: *The carriers were destroyed by 3 frigates and subs in the Indian Ocean*, in which ambiguity specialists for NP conjunction, PP clause attachment and quantifier scope will interact. This kind of interaction among specialists is a topic for our current research on effective paraphrasing.

5.4.2 Phase 2: Translating from WML to Text Structure

Once the Problem Recognizers have annotated the WML, the text planner takes over to translate the intensional logic expression into the hierarchical text structure which organizes the objects and relations specified. In this example, since the input was ambiguous and there are two WMLs, there are two possible strategies for paraphrasing which apply at this step:

- (1) Paraphrase of each interpretation separately (as discussed in Section 5.2).
- (2) Combine them into a single paraphrase using formatting and highlighting to contrast the differences:

Display the carriers in the Indian Ocean and the frigates in the Indian Ocean

*or the carriers in the Indian Ocean
and all the frigates.*

We will focus here on the second strategy, that which combines the interpretations. The text planner will begin by translating one of the WMLs and when it reaches the subexpression that is annotated as being ambiguous, it will build a text structure object representing the disjunction of those subexpressions.

As discussed in Section 5.3.2, the translation to text structure uses both explicit and implicit information from the WML. In this case, the translation of first operator, bring-about builds a complex-event object marked as a command in the present tense and the agent is set to *you*. The domain model concept LIST provides the matrix verb (see text structure in Figure 11).

When the translation reaches the setof expression, a coordinate-relation object is built containing both subexpressions with the relation disjunction. It is also annotated "emphasize-contrast" to guide the later

decision making. As this node and its children are expanded, the annotation is passed down. When the translation reaches the individual conjuncts in the expression, it uses the annotation to decide how to expand the text structure for that object. In the case where the modifier distributes, the annotation blocks any optimization and ensures both conjuncts will be modified; in the case where it does not distribute, there are two possible strategies to eliminate the ambiguity:¹⁰

1) Manipulating the order of the conjuncts in the text structure:

- If only one of the conjuncts is modified and the modifier is realizable as a premodifier, then that conjunct should be placed second.
- If only one of the conjuncts is modified and the modifier is realizable as a postmodifier, then that conjunct should be placed first.

In this case, the paraphrase would be: *Display the frigates in the Indian Ocean and carriers.*

2) Adding a quantifier, such as "all", to the conjunct without modification by adding an adjunct DO to the second conjunct, which would result in the paraphrase: *Display all the carriers and the frigates in the Indian Ocean.*

We use a combination of these strategies. The figure below shows the text structure built for this expression¹¹.

Once this level is complete, it is traversed and the linguistic resources, such as the lexical heads and major syntactic categories, are chosen and represented in the input specification to the linguistic realization component, Mumble-86, which produces the final text.

¹⁰Note that in this task of paraphrasing queries, where it is crucial that the paraphrase be unambiguous, these are strategies the generator should apply regardless of whether the original was ambiguous or not, as ambiguity may have been introduced into a conjunction by some other strategy, such as lexical choice.

¹¹Objects labeled DO in the diagram indicate discourse objects which have been created for this utterance. Objects labeled DM are objects from the domain model. The creation of discourse objects allows objects to be annotated with their roles and other information not contained in the domain model (tense, number) and introduces objects which can be referred back to anaphorically with pronouns (e.g. "they" for the DO dominating the conjuncts).

5.5 Using the Paraphraser in a Cooperative Dialog System

The work presented here has focused on developing strategies for paraphrasing in order to resolve ambiguity. However, in an actual NL dialog system, choosing when and how to use this capability can be based on other considerations. In this section we address some practical issues and some related work we have done in the integration of our paraphraser into a Man-Machine Interface.

The presentation of a paraphrase can be useful even in cases where no ambiguity has been detected, as it allows the user to verify that the system's interpretation does not differ from the intended interpretation. This is particularly useful for new users who need to be reassured of the system's performance. This feature should be under the user's control, though, since frequent users of the system may only want to see paraphrases when the system finds multiple interpretations.

Paraphrasing can also be incorporated in cooperative responses in order to make any presuppositions explicit. Consider the following exchange:

U: Display all the carriers.
S: <icons displayed on map>
U: Which are within 500 miles of Hawaii?
S: Carriers Midway, Coral Sea, and Saratoga.
U: Which have the highest readiness ratings?
S: Of the carriers within 500 miles of Hawaii, Midway and Saratoga are C1.

Incorporating elided elements from previous queries in the response makes clear which set is being considered for the current answer.

Another sort of paraphrase, which we term "diagnostic responses", can be used when the system is unable to find any interpretation of the user's query, whether due to ill-formedness, novel use of language, or simply inadequate information in the underlying program. As in paraphrasing, the generator uses structures built by the understanding component to generate a focused response. For example, a metaphorical use of "commander" to refer to ships, as in the following query will violate the semantic restrictions on the arguments to the verb "assign". When IRUS-II fails to find a semantic interpretation, it saves its state, which can then be used by the generator to produce an appropriate response:

Q: Which commanders are assigned to SPA 2?
S: I don't understand how commanders can be assigned.

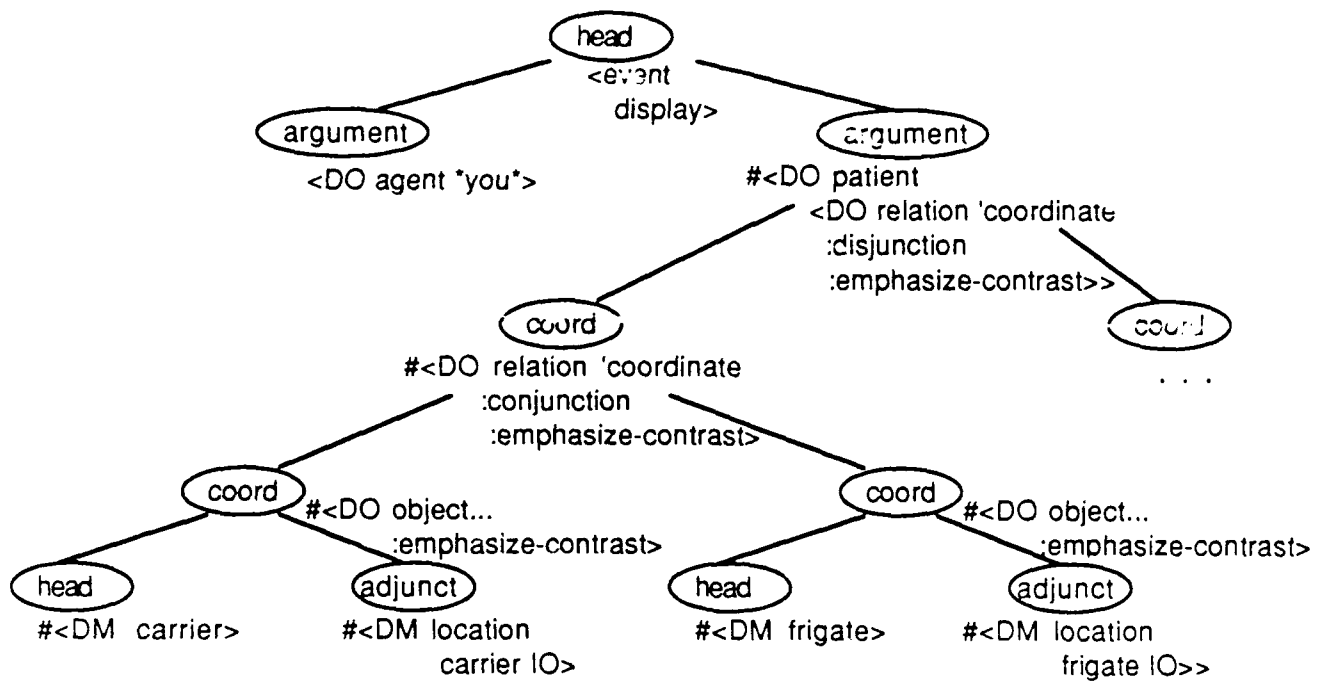


Figure 11: Text Structure

5.6 Comparison with Other Work

A similar approach to ours is McKeown's Co-op system (McKeown, 1983). It too functions in an interactive environment. However, it is limited in several ways:

1. Since the system it worked with was limited to data base queries, it could only paraphrase questions. This is not only a limitation in functionality, but affects the linguistic competence as well: the input had to be simple WH-questions with SVO structure, no complex sentences or complicated adjuncts.
2. It had only one strategy to change the text: given and new¹², which fronted noun phrases with relative clauses or prepositional phrases that appeared in the later parts of the sentence (essentially the verb phrase). For example *Which programmers worked on oceanography projects in 1972?* would be paraphrased: *Assuming that there were oceanography projects in 1972, which programmers worked on those projects?*
3. Since its only strategy involved complex noun phrases, if there were no complex noun phrases in the query, it would be "paraphrased" exactly as the original.

Lowden and de Roeck (1985) also address the problem of paraphrasing in the context of data base query. However, while they assume some parse of a query has taken place, the work focuses entirely on the generation portion of the problem. In fact, they define paraphrasing as providing a "mapping between an underlying formal representation and an NL text." They discuss in detail how text formatting can improve clarity and a solid underlying linguistic framework (in their case lexical functional grammar) can insure grammaticality. However, while they state that a paraphrase should be unambiguous, they do not address how to recognize when a query is ambiguous or how to generate an unambiguous query.

¹²A related problem is that its notion of given and new was very simplistic: it is purely based on syntactic criteria of the incoming sentence and does not consider other criteria such as definiteness of context

The BBN Parlance™ NL Interface is one of the most robust NL interfaces in existence. Its paraphraser integrates both the system's conceptual and procedural understanding of NL queries. This approach is based on the observation that users need to be shown the conceptual denotation of a word or phrase (e.g., "clerical employee") with its denotation in the underlying database system (e.g., an employee whose EEO category is 3 or an EE whose job title is "secretary"). Thus, the Parlance paraphrases incorporate references to specific fields and values in the underlying data base system. The structure of the paraphrased text closely resembles the structure of the interpretation of the query. So, while the text can be cumbersome, it has the advantage of more directly capturing what the system understood. Due to efficiency considerations and limitations on the space for output, the Parlance paraphraser presents the paraphrases one at a time, allowing the user to confirm or reject the current interpretation, rather than presenting all paraphrases at the same time. The system allows the user to refer back to previously presented interpretations, but as is the case with the other paraphrasers, related interpretations are not contrasted.

5.7 Conclusion

In addition to being useful in current interactive natural language interfaces, the paraphrase task provides an excellent context to explore interesting issues in both natural language understanding and generation as well as paraphrasing itself. In the next phase of our research we plan to look at quantifier scope ambiguities, lexical choice, and the interaction between multiple problems and strategies for improvement.

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